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COVER PHOTO:

One of the first highly detailed photographs of the entire sun to be taken in extreme ultraviolet light by a novel camera which was carried to an altitude of 123 miles above the White Sands Missile Range, N.M., by an Aerobee-Hi rocket. This camera is the result of four years of development at the U.S. Naval Research Laboratory.

Official United States Navy photograph.

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# Theory and Design of a Mechanical Blackbody for Solar Radiation

By P. L. Winskell and S. T. Hsu

Department of Mechanical Engineering, University of Wisconsin, Madison

**A method of increasing the absorptivity of a metallic surface by a mechanical arrangement of the surface is discussed in the paper. The theoretical absorptivities obtained as a result of varying such physical parameters as surface length, distance between surfaces, surface absorptivity, and angle of incidence of radiation are stated. An experimental heat exchanger and a mechanical blackbody surface are evaluated relative to a comparative heat exchanger and a coated black surface. An apparent increase in absorptivity is seen as the net heat transfer rate occurring with the mechanical blackbody (material absorptivity of 0.5) is 90 per cent of the rate obtained with the black surface.**

## INTRODUCTION

One of the current problems in the field of solar energy utilization is to obtain a durable, high absorptive, low emissive surface to solar radiation. The surface should be able to withstand the high temperatures resulting from the use of focusing devices. Some recent applications include solar cookers and solar furnaces.

In the first place, the problem of durability is two-fold. The surface must:

- withstand high temperatures, i.e., remain chemically stable, and
- resist mechanical damage from field usage.

Secondly, the absorptivity should be high, to obtain maximum efficiency, with the coincident reduction of solar collection areas, heat transfer areas, and heat transfer losses. Similarly, the material cost would be reduced.

To date, none of our common materials and/or applied coatings can satisfy adequately both aspects of this problem.

In an effort to find a solution to this need, an application of the classical definition of a "blackbody" was investigated. This definition states that a blackbody absorbs all radiation falling upon it and is commonly depicted as the area of a small hole in a hollow sphere

when radiation is incident upon the sphere. By continued reflections and absorptions, the initial radiation entering through the hole is reduced almost to zero; thus the complete or perfect absorption property of the surface area of the hole.

The initial premise was that a parallelepiped element or elements could be substituted for the usual sphere, and the performance predicted. If this were true, the absorptivity of the material was then not of such paramount importance, and ordinary durable metals could be used.

Phase I of the study consisted of the calculations of expected performance when such parameters of the parallelepiped element as length, width, material absorptivity, and angle of incidence were varied.

Phase II of the study then was the testing of an experimental surface and its comparison with a surface of known absorptivity (to solar radiation) and emissivity. The net heat transfer of the two surfaces was compared.

Phase III was an analysis of the obtained performance versus the predicted performance and includes observations on the variations.

## PHASE I: THEORETICAL CONSIDERATION OF MECHANICAL BLACKBODY SURFACES

### Absorptivity

Our initial premise was that the "sphere" could be replaced by a parallelepiped element or elements, and the investigation that follows includes predicted absorptivity based on this hypothesis. The two-dimensional form is depicted in Fig. 1, with action at any depth perpendicular to this view to be also co-planar and repetitious.

The validity of reducing the apparent three-dimensional case to two-dimensional analysis is based on three assumptions: (1) the radiation is direct solar radiation and not diffuse sky radiation; (2) the radiation can be pictured as parallel lines because of the great distance between the source (sun) and the receiver (absorption surface); (3) as an aid to analysis, the reflection of the radiation will be specular, as is the case for smooth surfaces, rather than diffuse, as for

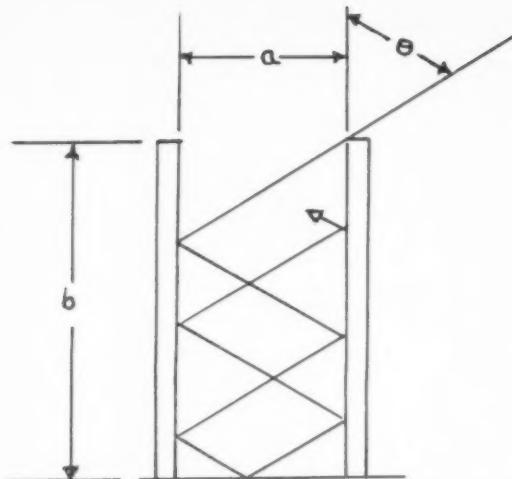


FIG. 1—Parallelepiped element of a mechanical blackbody.

rough surfaces, and will obey the general laws of optics.

The radiation wave arrives at the surface of the material at the angle  $\theta$ , as shown in Fig. 1. The inside distance between the parallel surfaces is  $a$ , and the length of the surface is  $b$ . The absorptivity of the surface to the arriving radiation is denoted by  $\alpha$ .

By the use of geometry, the number of reflections,  $n$ , of a single ray of radiant energy as it travels down the length of the element and back by successive reflections is found to be equal to  $2[b/a(\tan \theta)]$ .

If  $\alpha$  represents the absorptivity of the surface, the strength of the radiant energy is decreased by this amount at each point of reflection and coincident absorption.

Using the statements of the two preceding paragraphs, the total absorptivity of the element is found to be equal to  $1 - (1 - \alpha)^n$ .

This equation for the total absorptivity then allows one to determine theoretically the absorptivity for a given element when the physical parameters and the material are known.

On this basis, graphs such as those shown in Figs. 2, 3, 4, 5, and 6 were prepared showing total absorptivity when the length-width ratio,  $(b/a)$ , angle of incidence, and material surface absorptivity were varied. These can, ideally, serve as a design aid in that for a given selected material, the dimensions required and the angle of incidence necessary for operation can be found.

Conversely, where geographical or installation requirements determine the angle of incidence, the required absorptivity of the material that will give the desired total absorptivity can be determined for a given length-width ratio.

As such factors as specific heat, thermal conductivity, and cost will also have to be considered in an ultimate design, the apparent freedom in the choice of these variables is somewhat reduced, but is still considerable.

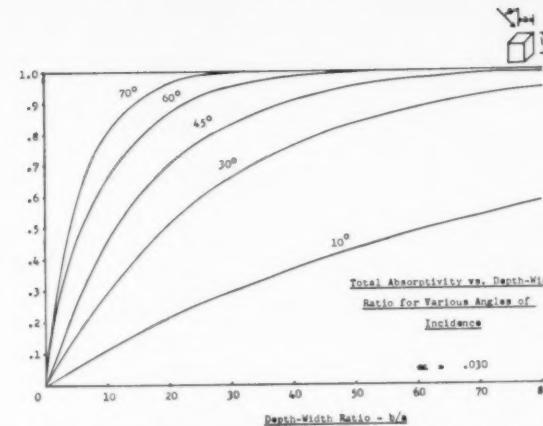


FIG. 2—Total absorptivity vs. depth-wide ratio for various angles of incidence.

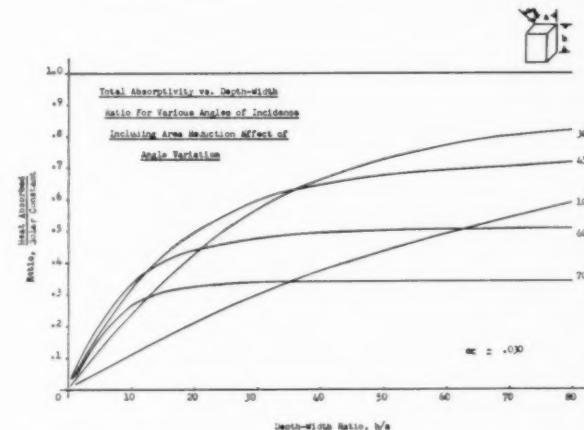


FIG. 3—Total absorptivity vs. depth-width ratio for various angles of incidence including area reduction effect of angle variation.

#### Possible Qualification on the Usage of Mechanical Blackbody Surfaces

The calculations of Phase I show that the absorptivity of a mechanical blackbody surface varies as the tangent of the angle of radiation, measured from an axis perpendicular to the surface, as shown in the expression.

$$\frac{b}{a} \tan \theta$$

$$\text{Absorptivity} = 1 - (1 - \alpha)$$

It should be noted also that as  $\theta$  varies the area of radiation intercepted by a given surface varies as the cosine of  $\theta$ . This has the following over-all effect:

Total energy absorbed (Btu/hr) equals the solar radiation constant (Btu/hr - sq ft)  $\times$  area (sq ft)  $\times$  absorptivity  $\times$   $\cos \theta$ .

$$Q_{\text{abs}} = Q_{\text{rad}} A_{\text{rea}} \left[ 1 - (1 - \alpha) \frac{2b \tan \theta}{a} \right] \cos \theta$$

This change in the amount of radiation intercepted

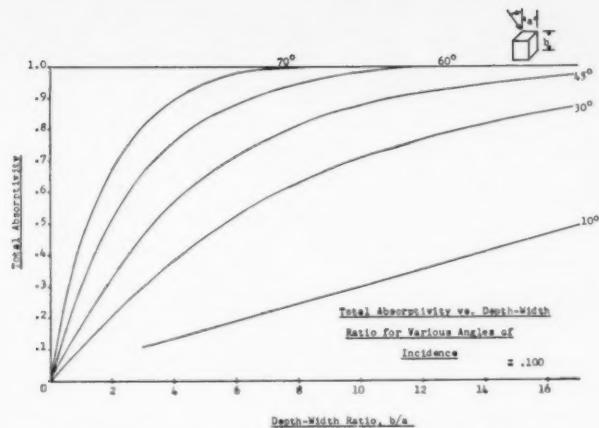


FIG. 4—Total absorptivity vs. depth-width ratio for various angles of incidence.

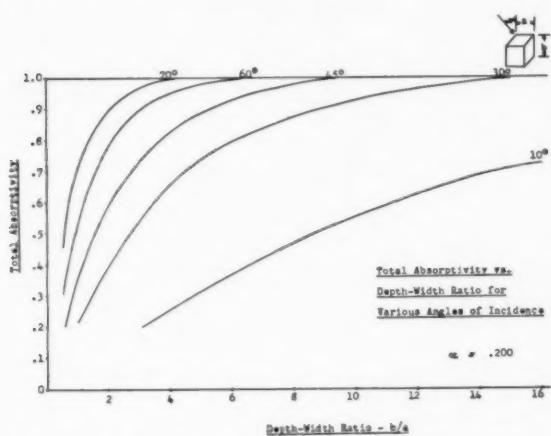


FIG. 5—Total absorptivity vs. depth-width ratio for various angles of incidence.

(seen) by the surface can be estimated by comparing Fig. 2 with Fig. 3. The optimum point of operation (angle of surface to radiation) can be selected for any exchanger. The angle is a function of the physical dimensions, length ( $b$ ) of the fin, and distance ( $a$ ) between fins.

While the proposed design is considered as a blackbody for absorption purposes, it was also investigated for radiation loss (emission) on the same basis as a blackbody.

The Stefan-Boltzmann law  $Q = \sigma A T^4$  gives the maximum value for the radiation heat loss. Any other material or substance will radiate a quantity less than the blackbody. Thus we have a limiting case in this heat loss prediction, and any actual design can have only a lesser heat loss by this method of heat transmission.

TABLE I

degrees F.	0	100	200	300	400	500	600	700	800	900	1000
$Q$ , Btu/hr-ft <sup>2</sup>	78	172	330	581	950	1470	2190	3150	4400	5950	8000

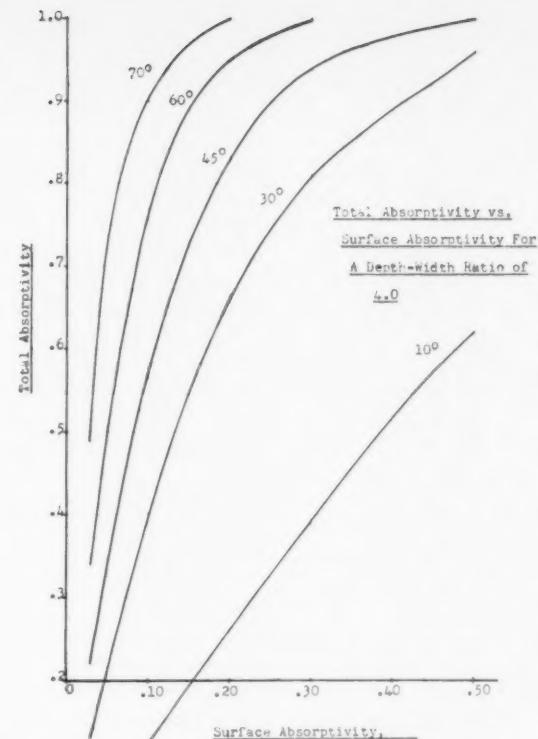


FIG. 6—Total absorptivity vs. surface absorptivity for a depth-width ratio of 4.0.

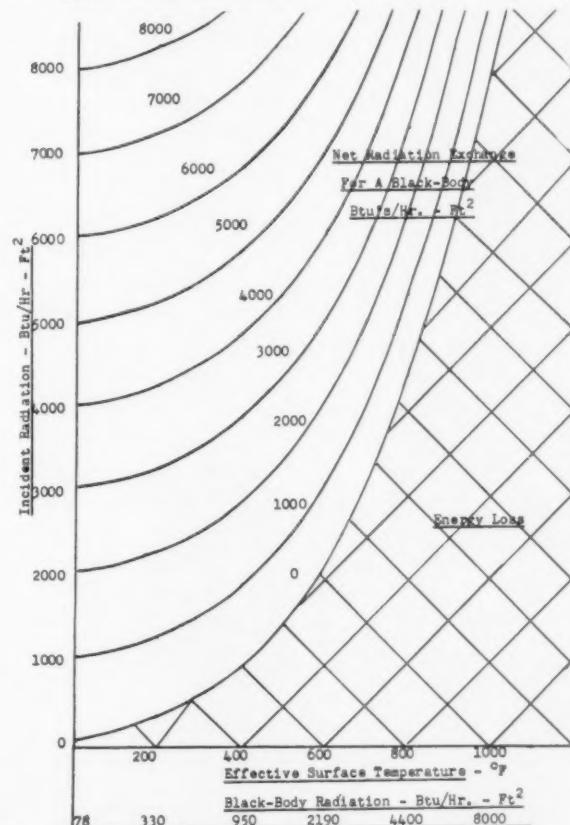


FIG. 7—Net radiation exchange for a blackbody, Btu per sq ft-hr.

The blackbody radiation loss for typical surface temperatures are given in Table I.

Consideration of the effect of these blackbody radiation losses is shown in Fig. 7. The value in low surface temperatures is shown pictorially, and the net gain due to the higher absorptivity is realized when the higher incident radiation values are used.

## PHASE II: ACTUAL PERFORMANCE OF AN EXPERIMENTAL MECHANICAL BLACKBODY SURFACE

### Description of Apparatus

Three heat exchangers were fabricated in cylindrical form with conical upper sections, two being for comparative purposes, with flat circular areas for the solar absorption surfaces. The third heat exchanger was constructed similarly in size and shape, with the solar absorption surface of the proposed mechanical type.

The length-width ratio used in the mechanical experimental surface was 4.0, meaning the length of the surface (fin) from the exposed end to the point of contact at the heat exchange surface was four times the distance between fins. The actual dimensions used in this design were 2.0 and 0.5 in. respectively. (Theoretical absorptivities for  $B/A$  ratio of 4 are shown in Fig. 6.)

The comparative heat exchangers were identical in construction. Copper sheet of 0.100 in. thickness constituted the cylindrical and conical sections. The flat circular section is of 0.125 in. thick brass plate.

These exchangers were differentiated only by one having the brass surface coated with a thin black coating of copper oxide, a material which was investigated for solar energy absorption purposes by the Department of Chemistry and the Solar Energy Laboratory of the University of Wisconsin.

The third (experimental) cylinder was similar in construction to the comparative exchangers, but differed by the dimensions of the added mechanical absorption

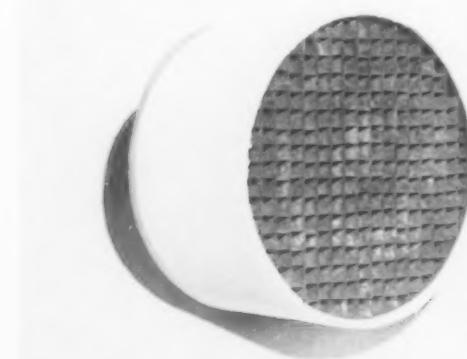
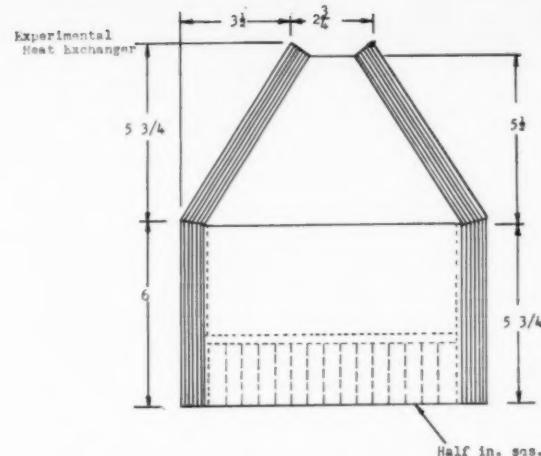


FIG. 8—Experimental blackbody surface and heat exchanger.



Material: Copper  
Wt: (Uninsulated) 13.8#

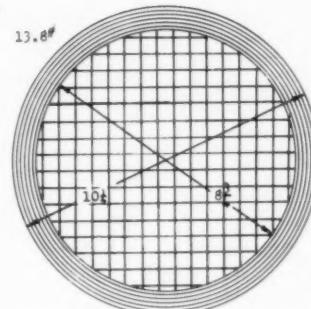


FIG. 9—Experimental blackbody surface and heat exchanger.

surface, which was 2 in. in depth. As shown in Figs. 8 and 9, the fins, which are at right angles to each other and to the brass plate in this construction, were made of 0.010-in. polished brass shim stock which during the assembly (soldering) operation reached a temperature of approximately 400°F. This temperature caused oxidation of the brass surface to a certain extent.

Although the exact solar absorptivity of this particular fin material was not measured, earlier investigations by the above-mentioned groups showed the absorptivity of polished brass and copper surfaces to be 0.35 and 0.27, respectively. A corresponding value for unpolished copper is 0.52.

Initially all three heat exchangers were as described. After the first test, described later,  $\frac{3}{8}$ -in. of asbestos insulation was added to the outer surface, and then again, later,  $\frac{3}{8}$ -in. more insulation plus aluminum foil completed the heat exchangers. The insulation was added to reduce the heat transfer at the outer surface, and the aluminum foil to reduce direct solar absorption on the surface. These two are not in contradiction because of the physical arrangement of the test apparatus. (See Fig. 10.)

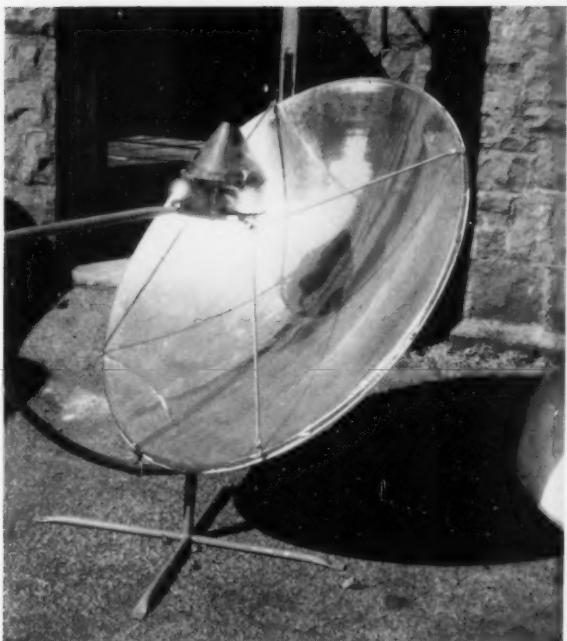


FIG. 10—Test apparatus, showing 4-ft diameter reflector stand and uninsulated heat exchanger.

### Method of Testing

The approach taken in the evaluation of the solar absorption surfaces was to equalize rather than to eliminate the associated heat losses.

The net heat transfer, taken as the difference between the energy absorbed and energy radiated, was determined by the temperature rise of a fluid (water) in the heat exchangers, neglecting convection and radiation losses on the outer surface on the basis that they were equal. This method was chosen to obtain relative performance to a known surface rather than an absolute determination of absorptivity and emissivity.

The following block diagrams, Fig. 11(a) and (b), illustrate the assumption of neglecting the heat loss by

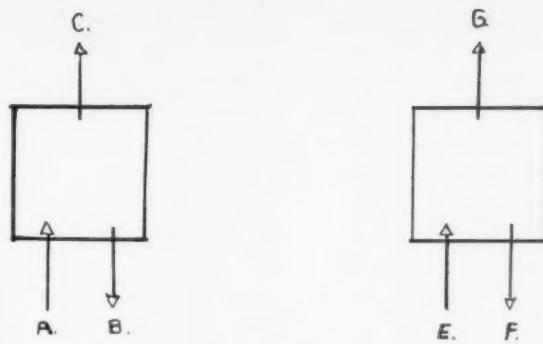


FIG. 11.

convection and radiation on the outer surface and the possible fallacy in this procedure.

$A$  and  $E$  = energy absorbed at the bottom surface.

$B$  and  $F$  = energy emitted at the bottom surface.

$C$  and  $G$  = convection and radiation loss from the side wall and top of heat exchanger.

$D$  and  $H$  = net energy absorbed

$$D = A - (B + C) \quad H = E - (F + G)$$

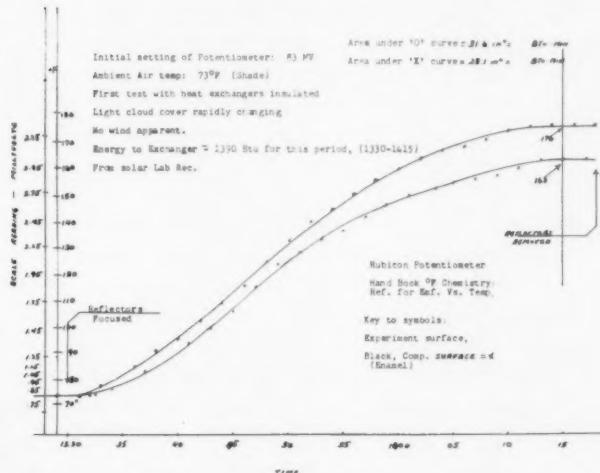


FIG. 12—Water temperature in heat exchanger vs. time.

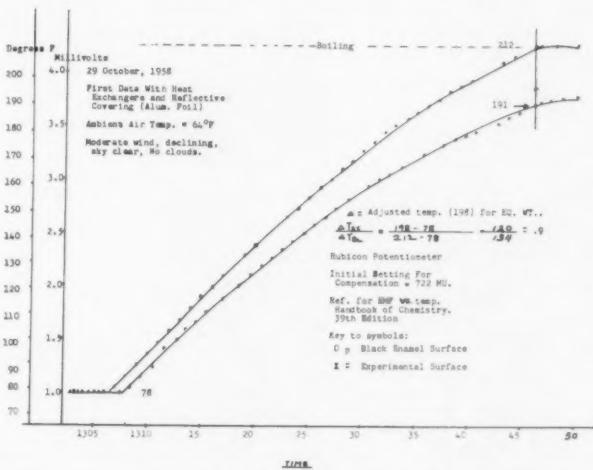


FIG. 13—Water temperature in heat exchanger vs. time.

If  $C$  is assumed equal to  $G$ ,  $D$  and  $H$  are proportional (equal) to  $(A - B)$  and  $(E - F)$ , respectively. But  $C$  and  $G$  are functions of  $D$  and  $H$  and corresponding temperatures on the outer surface.

The reflectors as shown in Fig. 10 were operated and adjusted continuously to keep the focus of the reflection in the center of the absorption surface. The temperature of the water in the heat exchanger was recorded at intervals of 30 seconds and/or one minute. The data of water temperatures versus time are shown on the graphs of Figs. 12 and 13. All variables were kept as equal as possible during the test interval. Such factors as simultaneous adjustment of the reflectors to the absorption surfaces, equal surface conditions of reflectors, and equal weights of water were included in this effort to obtain equalization.

As shown in Fig. 10, the radiant energy of the sun was reflected and focused on the absorptive surfaces by means of 4-ft diameter parabolic reflectors which were of high-impact polystrene plastic and covered with a 0.001-in. thick mylar film.

The reflector can be pivoted about an axis which is approximately through the focal point of the reflector, so as to be at the angle required to focus the radiation on the absorptive surface. A second vertical axis allows reflector movement as required by motion of the sun.

### Test Results

As previously stated, the method of testing was to compare the over-all heat transfer of the different exchangers and surfaces and thus reach a value of effectiveness of the experimental surface relative to a known surface.

The heat transferred to the water is the product of the factors: weight of water, specific heat, and temperature rise. The heat transferred is equal to the difference of heat absorbed minus the losses due to convection and radiation of both the absorption surface and the outer surface of the exchanger. The type of reasoning does not allow the absolute determination of absorptivity but gives the ratio of net heat transfer rates.

The heat losses for the outer surfaces were considered to be equal and thus omitted. Whereas the losses, both convection and radiation, would be higher with the exchanger with the black comparative surface because of the higher temperature, this would be offset by the larger area of the experimental exchanger. The values of  $Q$  (net heat transferred to the water) then include all convection and radiation losses. The ratio of  $Q$  values is considered to exclude outer surface convection and radiation losses on the before-mentioned assumption.

The ratio of heat transferred by the experimental surface to that by the black comparative surfaces was found to be 0.92, 0.85, 0.90, and 0.84. The ratio of heat

transferred by the experimental surface to that of the unpolished brass surface is 1.4 or, vice versa, 0.71.

A supplementary test was made on the surfaces by use of a General Electric radiometer which is sensitive to the solar spectrum only.

Direct exposure to the sun gave a radiation value of 0.85 gm-cal per sq cm-min. Reflection from the black comparative exchanger which was placed normal to the sun gave a scale reading of 0.05. The mechanical surface gave the same reading (0.05) as accurately as could be determined with the large scale increments (0.10).

Because of this scale-accuracy problem the 0.05 readings cannot be used absolutely, but the point that the two surfaces recorded approximately equal reflections, and thus absorptivities, is significant and is in agreement with the previous test data. At the same time a further correlation was made by comparison to a polished brass surface of which the absorptivity was known.

### PHASE III: COMPARISON OF THE THEORETICAL VALUES WITH THE EXPERIMENTAL RESULT

#### Value of a Blackbody Surface

A question that logically arises now is: "If the proposed mechanical arrangement acts as a blackbody with respect to the incident radiation, does it also behave as a blackbody radiator or source of emission?"

We would expect so, theoretically.

The blackbody radiation values are given in Phase I. These values represent a maximum heat radiation loss as any other body will radiate a lesser amount.

Next, if this maximum occurs, does this loss reduce the net heat gain to a value below that which now can be obtained by some of the presently used coatings and/or materials?

As an example of current materials and their performance, the investigations of Daniels and Salem give values of absorptivity to solar radiation and emissivity at some of the expected operating temperatures

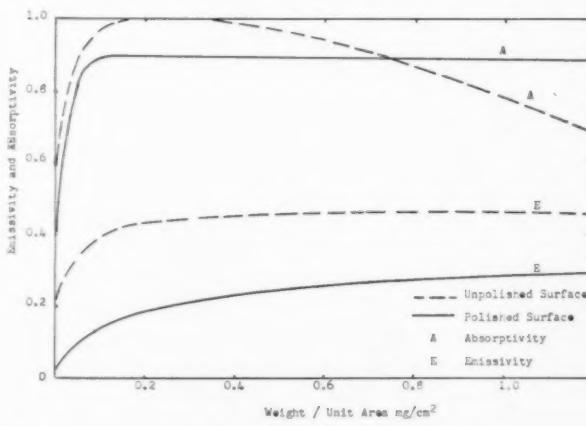


FIG. 14—Cupric oxide coatings on copper surfaces.

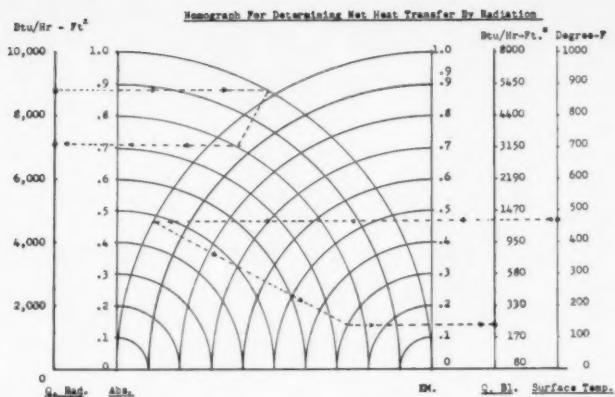


FIG. 15—Nomograph for determining net heat transfer by radiation.

of the surface for brass, copper, and copper oxide coatings. This information is given in Fig. 14.

The values of  $\alpha$  and  $\theta$  are defined as usual; the absorptivity and emissivity, respectively, of the surface is compared to a blackbody at the same temperature.

The net heat transfer away from the absorption surface by conduction is the desired effect. This, first neglecting convection heat losses, is the difference of two products of two different variables each: (incident radiation  $\times$  absorptivity) — (emissivity  $\times$  radiation of a blackbody at the same temperature).

The incident radiation can be varied by means of focusing or concentrating devices, in multiples of the solar constant.

The absorptivity and emissivity values will be a function of surface temperature. The radiation of a blackbody is a function of the fourth power of the absolute temperature.

The following nomograph has been constructed to facilitate the evaluation of this net heat transfer and to enable one to see pictorially the effect of these variables. Use of the nomograph is as follows (Fig. 15):

- (1) Select the known heat flux, Btu per sq ft-hr, for the given amount of solar radiation and reflector magnification (ordinate at extreme left).
- (2) At an absorptivity of unity, rotate clockwise on the arc until a point is reached at an equal ordinate to the value of (1).
- (3) At the intersection of this radius and the arc corresponding to the absorptivity of the material, move horizontally to the left to find the heat absorbed.
- (4) Select the absorption surface temperature (ordinate at extreme right).
- (5) At an emissivity of unity, rotate counter-clockwise on the arc until at an equal ordinate to the value of (4).
- (6) At the intersection of this radius and the arc corresponding to the emissivity of the surface,

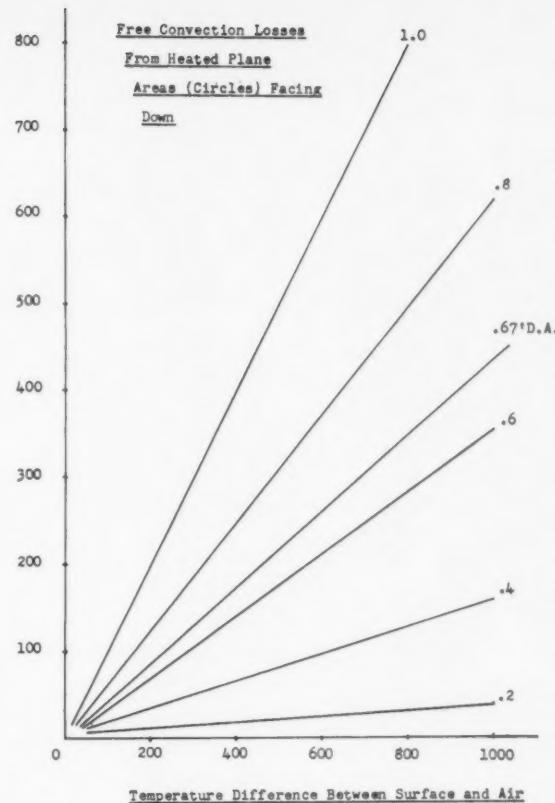


FIG. 16—Free convection losses from heated plane areas (circles) facing down.

move horizontally to the right to the second ordinate to find the heat radiated.

- (7) The difference in the values of heat absorbed (3) and heat radiated (6) is the net heat transfer for the surface.

#### Heat Convection on a Plane Horizontal Surface

A second possible occurrence is that the convection loss associated with plane horizontal surfaces (the black comparative surface in our test) is not experienced by the mechanical blackbody surface because of the small (negligible) area at the ends of the fins.

The magnitude of these free convection losses from a heated plane surface facing down is shown in Fig. 16. The appropriate coefficient of convection heat transfer is

$$h_c = 0.12 \left( \frac{\Delta t}{L} \right)^{0.25}$$

where:

$\Delta t$  = temperature difference between the surface and the surrounding air.

$L$  = length of the surface (ft).

For the black comparative 8-in. diameter surface and a temperature difference of 200° between surface and air, the loss in Btu per hr would be equal to (1.183) (0.35) (200) or 83 Btu per hr.

TABLE II

	Comparative	Experimental
Oct. 13	865	800
Oct. 20	475	390
Oct. 28	615	568
Oct. 29	450	640
Nov. 10	670	655

The actual net heat transfer rates for the comparative and experimental surfaces in Btu per hr are shown in Table II.

For the comparative surfaces, then, the suggested free convection heat losses represent 9.5 per cent to 18.5 per cent of the net heat transferred, on the basis of a  $200^{\circ}$  temperature difference.

(The comparative exchanger used for the Oct. 29 test had a polished brass surface; all others had the black cupric oxide coating.)

### SUMMARY

Theoretically, high absorptivity values can be obtained by mechanical arrangement of surfaces to promote the continuous reflection and absorption of radiation. This value of absorptivity is a function of the number of reflections and the surface absorptivity. Further, the number of reflections varies as the length of surface, distance between surfaces, and the angle of radiation incident to the surface.

The test results from the evaluation of an experimental mechanical blackbody surface have added impetus to this hypothesis. The net heat quantity trans-

ferred by this mechanical surface averaged 0.9 that of the quantity transferred by a comparative black surface which had the known absolute properties of absorptivity to solar radiation of 0.90 and an emissivity at  $110^{\circ}\text{C}$  of 0.20.

The material used in the mechanical blackbody has an absorptivity to solar radiation of approximately 0.50 and an emissivity at  $110^{\circ}\text{C}$  of 0.20.

The exact change in the values of absorptivity and emissivity is undetermined, but rather the relative overall change in efficiency, which included radiation and convection losses, was investigated in the experimental phase of this study.

The possibilities for this apparent gain of the blackbody surface are:

- (1) an increase in absorptivity, as theorized, without appreciable increase in emissivity,
- (2) an increase in absorptivity and emissivity, coincident with a reduction in convection losses because of the mechanical arrangement of the surfaces of the blackbody,
- (3) comparison to a standard which is not as high as believed.

As the material used in the experimental mechanical surface had a relatively high absorptivity, the resultant high net heat transfer value which was obtained is not so convincing as a similar value obtained with surface material of low absorptivity. It is suggested on the basis of the performance observed that experimental work be continued through a wide range of variables to further substantiate the proposed mechanical blackbody.

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# Selective Surfaces and Solar Absorbers

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**This paper deals with the emission characteristics of the sun and artificial radiation sources, the absorbing and transmitting properties of materials, and how these properties of materials can be analyzed and used to advantage in solar energy collectors. The actual performance of these surfaces is predicted from spectral data and then compared with actual results obtained with artificial sources indoors and the sun as source outdoors.**

## INTRODUCTION

With the tremendous progress made in interplanetary space exploration and with the advent of space travel near at hand, interest has greatly increased in the control and utilization of the energy from the sun. This energy coming from the sun and falling upon a space vehicle such as a rocket or satellite must be controlled to keep the environmental conditions inside such vehicles tolerable and if possible to use some of the incoming energy for useful purposes.

This may mean that the correct proportions of solar energy (possibly even within certain wavelengths) must be absorbed or reflected to obtain the desired temperatures and to provide energy for propulsion purposes, for refrigeration, and possibly for food production. Energy of the whole solar spectrum or only energy in certain bands may be desirable.

If the results as outlined above are to be obtained, it is necessary to be able to reflect, absorb, or filter the incoming energy as required.

A great deal of very valuable information has been presented in literature regarding the collection of solar energy, the main objective in every case being to design and obtain the best possible collector. This paper will present a systematic approach for selecting the best of the available materials based upon spectral emission, transmission, and absorption data. These results are then compared with experimental data of energy collected, first with an artificial source and then with the sun.

Indoor experiments have the great advantage of being independent of the weather and thus perfectly

reproducible, and, furthermore, results can be obtained any time of day or night. The sun irradiation experiments are much more difficult to carry out since they are affected by weather and the seasons. The best data with the sun were taken around noon and only on perfectly clear days. In spite of the difficulty with the outdoor experiments, such as varying wind velocities and air temperatures, the results are considered very satisfactory.

## COLLECTION OF RADIANT ENERGY

One objective in the utilization of solar energy is to collect as much of the incoming energy as possible. Having available a great variety of materials with widely differing properties, different designs can be used to take the best advantage of these properties.

Energy can be collected as shown in Fig. 1A, where most of the incoming energy is absorbed and only a small amount of energy reflected and radiated by the surface. Such a surface is a selective surface, and the difference between the incoming and outgoing energy becomes available to us. Practically all surfaces found in nature are selective to a certain degree and under certain conditions. The problem here is to find substances or systems with high selectivity or high absorptivity.

If a particular surface does not have enough selectivity, one or more filters can be added (Fig. 1B), which will let the energy coming from the source hit the absorbing surface, but then prevent the energy radiated from this surface from escaping.

The filter does this by both reflecting part and absorbing part of the energy radiated from the surface. A great number of filter materials can be used, both of the solid and liquid type, to form a highly selective

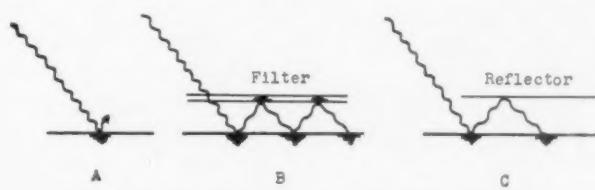


FIG. 1—Methods for absorbing solar energy.

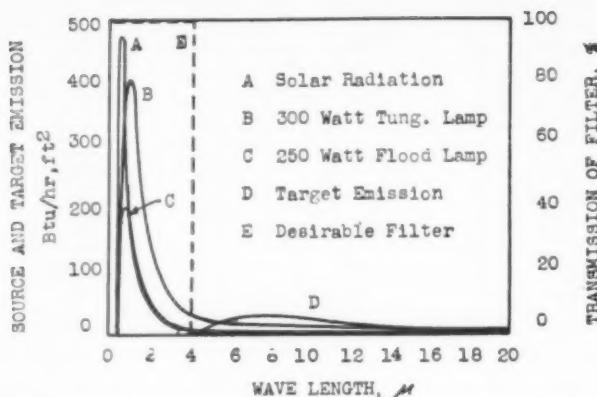


FIG. 2—Spectral emission, transmission, and absorption.

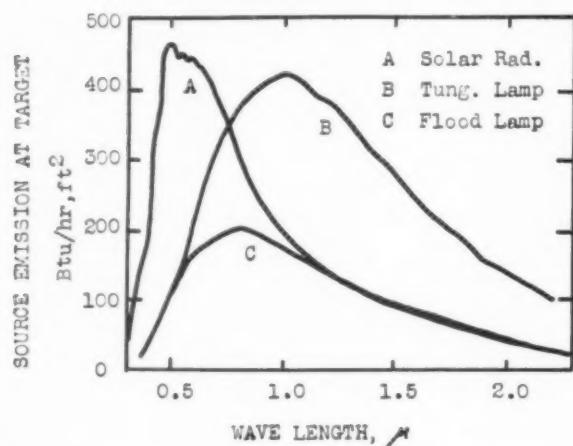


FIG. 3—Spectral energy distribution of different sources.

system when combined with an otherwise not very selective surface.

Since a number of materials are good reflectors, this property can be used in a solar energy collector by re-reflecting the energy toward the absorbing surface and thus preventing it from escaping. (See Fig. 1C.) This arrangement can be repeated any number of times; for instance, the surfaces can be stacked one on top of the other. In this design it would be possible to use a material which is a good reflector on one side and a good absorber on the other.

The characteristics of materials used as sources, as filters, and as absorbers or reflectors will be discussed later in this paper. It is, however, only possible to present here a small number of substances, their properties, and the test results.

For the results reported in this paper all irradiation was normal to the surfaces. Studies have been made and are still underway investigating the effects of the angle of incoming radiation.\*

Fig. 2 gives a relative comparison between three sources, two of which have been used extensively. It

\* This information will be given in a later paper.

shows the characteristics of an ideal filter and also gives some idea about the energy radiated by the absorbing surface or target.

### ENERGY SOURCES

Since the objective of this investigation was to study the collection of solar energy, the sun represents the most important source. Its spectral emission characteristics, when the target is perpendicular to the sun's rays, the sun near the zenith, and the elevation only slightly above sea level, are shown in Fig. 3.

Since the sun is an unpredictable source, with the weather, seasons, and time of day playing a major role in its availability, other sources have been investigated. The one most used was a 300-watt tungsten lamp with a filament temperature at about 4600°F. The data are plotted for a target 1 ft from the lamp. It can be seen that because of the lower temperature of the lamp the spectrum is shifted to the right with regards to the solar spectrum. (See Fig. 2 and 3.)

Another source which was used here is the photo-flood lamp (about 5700°F), which approaches the solar spectrum closer. However, the life of these photo-flood lamps proved to be only about two hours, and they were discarded as a source. The data shown are for a 250-watt photo-flood lamp at a distance of 1 ft.

The desired irradiation intensity can be obtained by moving the target closer or further from the artificial sources.

### FILTERS

The characteristics of different materials which can be used as filters due to their selective spectral transmission are shown in Fig. 4. Among these are two liquids, water ( $\frac{1}{4}$ -in. layer), copper sulphate ( $\frac{1}{2}$ -in. layer, 10% solution); two glasses, solex heat-absorbing

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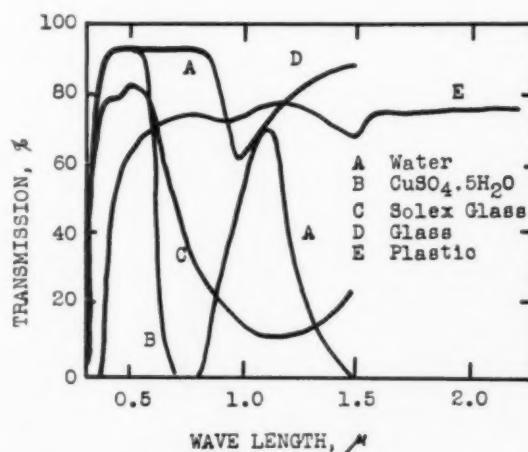


FIG. 4—Transmission spectra of different filters.

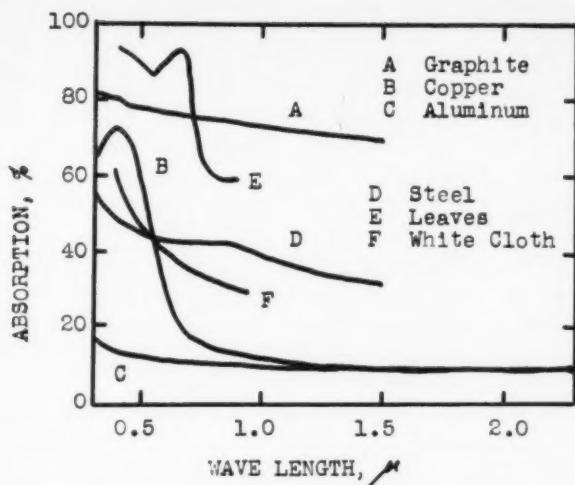


FIG. 5—Absorption spectra of different materials.

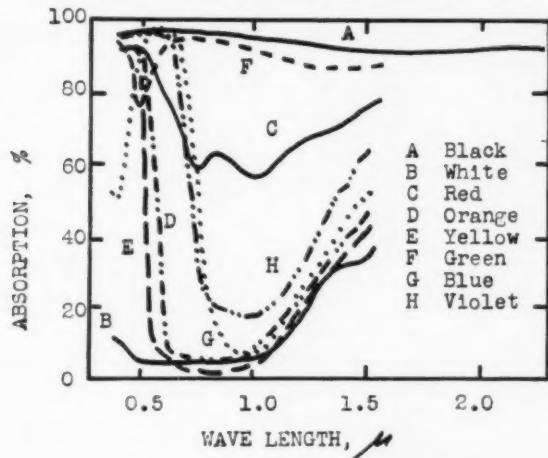


FIG. 6—Absorption spectra of different paints.

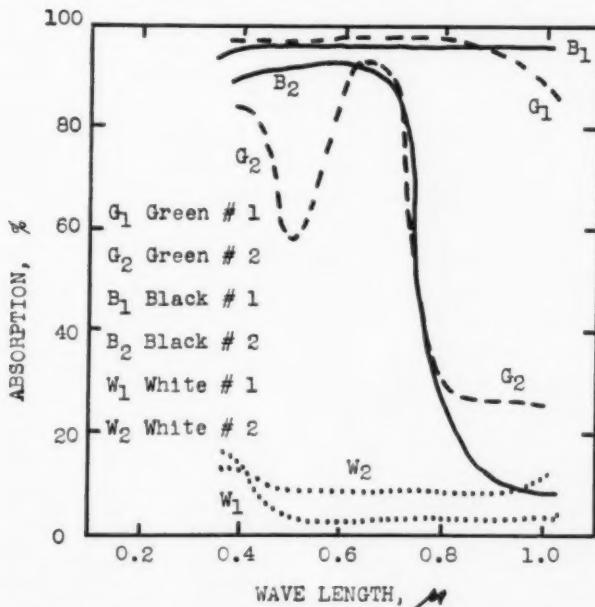


FIG. 7—Absorption spectra of black, white, and green paints.

glass (1-in. thick), heat-transmitting glass (0.1-in. thick); and finally one plastic (5 mills thick).

It can readily be seen from this figure that for solar energy collection, water, copper sulphate, and the heat-absorbing glass are the best of the filters shown. The heat-transmitting glass is the poorest.

#### ABSORBING SURFACES AND MATERIALS

Having discussed energy sources and filters, we shall now look at the absorption characteristics of materials. These characteristics for specific materials (polished metals, flat paints) are shown in Figs. 5, 6, and 7. The color of the paints should not be taken as the criterion since wide variations were observed within the same color, but it was most convenient to use the color as the over-all designation. The ones in Fig. 6 were selected, since they represented roughly the rainbow colors. That what are essentially the same colors can give absorption spectra of extreme difference can be seen by comparing the two green paints analyzed in Fig. 7. Thus factors (grain size, pigment, vehicle, etc.) other than or in addition to color are of greatest importance in determining the absorption and emission characteristics of surfaces.

Another interesting observation is the similarity of green paint G<sub>2</sub> and the spectral absorption of leaves.

#### EXPERIMENTAL PROCEDURE AND RESULTS

Much of the work described here was made with paints and colored pigments. Copper test panels were prepared, 6 in. by 6 in., and polished. These panels were then painted, following closely the manufacturers' recommendations, and allowed to dry slowly. Then their spectral diffuse reflection was obtained with a Beckman Quartz Spectrophotometer.

The results obtained with panels painted in this manner seemed to be of greater value than those obtained by fabricating specific laboratory surfaces of certain definite film thicknesses, which do not have much similarity to the actual surfaces which may be used. Three test panels of each kind were prepared in order to have a triple check upon performance.

These panels, with thermocouples attached to their back sides, were exposed individually to the artificial sources, and time was allowed for them to reach temperature equilibrium. For these equilibrium conditions the necessary data such as plate temperature, air temperature, temperature differential across insulation placed in back of the vertical plates, etc., were taken to allow calculation of the heat losses from the plate by standard heat transfer methods.

After the indoor tests had been completed, the plates were mounted together on a board and exposed to the sun, perpendicular to its rays. The temperatures were recorded continuously, moving from one panel to the

next. Again the heat losses from the plates were calculated by conventional methods. In these calculations it was, however, necessary to make a number of assumptions regarding the exact wind velocity, air temperature variation, etc., making the outdoor tests somewhat less reliable than the indoor experiments.

The experimental results have been tabulated in Table I along with the "theoretical" or predicted results from the spectral data of the various surfaces. They are given on a relative scale from 0 to 1, rather than in terms of the actual values or number of Btu absorbed, since the latter could be varied with the artificial sources by moving closer to or further from the source. Actual comparison on this relative scale is much easier.

### ANALYSIS

Before and during the time when the experimental work was carried out, the spectral data were analyzed and the absorption determined at each wavelength. With this information and data on the amount of energy falling upon the surface from a specific source, it was an easy matter to determine the amount of energy absorbed at this wavelength. Taking the energy absorbed at each wavelength for a specific source and summing it up over the whole range gives then the total amount of energy absorbed by this surface irradiated by the source.

This procedure was followed, as well as possible, for the different colored surfaces listed in Table I. These surfaces are designated by color only, since it was the simplest designation and one could select the surface under consideration with the least difficulty. Only one paint of each color is reported here. The color significance should not be overemphasized since great variations occur within the same color, even though the appearance is the same to the eye.

### DISCUSSION AND EVALUATION OF RESULTS

Looking at the results in Table I, it can be seen that the agreement between the "theoretical" predicted values, based upon the spectral characteristics of a specific source and a specific surface, agree satisfactorily with the results obtained experimentally.

TABLE I  
COMPARISON OF RESULTS

Source	Black	White	Red	Orange	Yellow	Green	Blue	Violet
Sun								
Spectral	0.96	0.23	0.75	0.47	0.38	0.91	0.65	0.64
Exptl.	0.93	0.32	0.80	0.55	0.43	0.94	0.72	0.70
Tung. lamp								
Spectral	0.94	0.43	0.76	0.49	0.45	0.90	0.57	0.60
Exptl.	0.95	0.49	0.81	0.52	0.50	0.92	0.60	0.61
Infra red								
Spectral								
Exptl.	0.95	0.92	0.95	0.93	0.93	0.92	0.94	0.94

It is also observed that the surfaces remained in their relative positions, except for blue and violet, whether the sun or the tungsten lamp was used. In other words, it seemed to be possible to select the best or poorest surface relatively easily and quickly by using a tungsten lamp as the source. If greater accuracy is desired, the spectral data should be used, as we can quantitatively predict the performance from it.

With infrared sources and electric hot plates set on end, the difference in performance disappeared, and it would have been very difficult to select the best absorbing or reflecting surface of solar energy with the hot plate as the source.

We also noticed that the experimental results seemed to be consistently somewhat higher than the "theoretical" results. Two reasons can be given for this difference.

(1) The complete spectrum for the absorbing surfaces was not known because of the limitations of the spectrophotometer. Even though the main part of the spectrum was determined, a portion of it had to be estimated.

(2) Assumptions had to be made regarding wind velocity, film coefficients, temperature fluctuations, etc., to make it possible to calculate the heat losses from the plates. These assumptions could easily have been somewhat conservative, giving heat losses that are somewhat high. From equilibrium considerations these heat losses must equal the energy absorbed by the plates.

This second reason seems to be even more likely when it is observed that the agreement between predicted and experimental results is better for the indoor tests, where the variables could be estimated better.

The performance of the infrared source could not be predicted since the range of wavelength at which radiation and absorption occurred was outside the range of the spectrophotometer and the analysis could not be made. Available data showed, however, that the spectra for the different surfaces used here approached each other in the infrared region—a fact also borne out by the similarity of the experimental results for the surfaces tested.

The effects reported here can be accentuated further or minimized by the addition of filters with the desired spectral characteristics. The usefulness of the filters can also be predicted from the spectral data. A layer of water on a polished metallic surface, for instance, proved to be of tremendous value by increasing the absorption capability of the surfaces. It increased on the average by about 80 per cent.

Many of the newer plastics are being investigated as possible filters for normal incidence; in addition, greater reflective powers at lower angles of incidence.

The type of finish, gloss, semigloss, and flat did not seem to influence the results greatly or consistently,

but further studies are underway, controlling such variables as grain size of pigment, pigment concentration, cover power, vehicle, etc.

### CONCLUSIONS

It seems that the following conclusions are justified, based upon the results obtained above:

(1) It was possible to predict actual experimental performance and results from the spectral characteristics of the source, filter, and absorbing surface.

(2) The results shown here allow a relative performance prediction of outdoor data by indoor experimentation. The relative position of the surfaces remained about the same in all except one case.

(3) It is believed that this systematic investigation allows a better understanding of the characteristics required for the successful utilization of solar energy and at the same time lends itself to an investigation of available data without having to set up outdoor tests, with all their uncontrollable variables.

(4) It was also possible to decide which surface will give a better performance when used outdoors by testing them quickly indoors with artificial sources.

### CLOSURE

It is believed that this systematic approach in predicting performance of selective surfaces and solar absorbers based upon spectral characteristics which are known or can be obtained relatively easily indoors will further progress greatly, since the investigation can be carried out 24 hours a day under controlled conditions unaffected by the variations of solar incidence, weather, and the seasons.

This approach also makes possible prediction of the performance of a surface or a combination of reflecting and absorbing surfaces and filters in outer space, where actual experimentation at this time is very difficult, if not impossible.

### REFERENCES

1. M. Jakob, *Heat transfer*. N.Y., Wiley, 1949. Vol. 1.
2. National Research Council, *International critical tables*. N.Y. & Lond., McGraw-Hill, 1929.
3. W. Clark, *Photography by infrared*. N.Y., Wiley, 1946.
4. H. A. Endres, "Optical properties of pigments in the visual and near infrared." *Official Digest, Federation Paint and Varnish Production Clubs*, 1943, No. 227: 202-16.
5. J. J. Mattiello, "Spectral characteristics of pigments in the visual and infra-red bands." (In: *Protective and decorative coatings*, N.Y., Wiley, 1945. Vol. 5.)

# Thermoelectric and Mechanical Conversion of Solar Power

By R. C. Schlichtig and J. A. Morris, Jr.

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**I**t has been frequently demonstrated that solar energy can produce power by its direct heating effect. It has previously been overlooked, however, that sunshine stores vast amounts of free energy in the atmosphere by lowering its relative humidity, particularly in desert areas. The presently described equipment is a composite of a solar collector, a thermoelectric generator, and a mechanical converter which will generate power from waste heat and stored free energy of dry atmospheric air.

The mechanical converter is unusual in its simplicity, its flexibility, and its capability to use small temperature differentials. Although the mechanical converter is described as associated with a reflecting solar collector, field tests may show the mechanical converter to be more practical without the collector, in which case air of the greatest usefulness would be collected from the surface of the solar heated ground by a grid of air ducts. Several cycle variations are possible with the same basic machine, which uses air as the working substance.

Although the use of salt or fresh water for evaporation improves the power output, the mechanical converter will operate without evaporating water if water cannot be obtained.

## INTRODUCTION

Solar energy falls on the earth's surface at the rate of approximately 80 watts per normal sq ft during clear atmospheric conditions. The energy is of such abundance that it could supply the electric power of the world. This energy is replaceable, unlike the energy of fossil fuels which is nonreplaceable. Many attempts have been made in the past to convert solar power to mechanical or electrical power. Mechanical converters historically took the form of steam engines, with boilers located at the focus of solar collecting reflectors. These primitive converters had very low efficiency because of excessive heat losses from the boilers if they

were operated at sufficiently high temperature to give reasonable thermal efficiency in the engines.<sup>3, 4, 6</sup> Recently, with the development of thermoelectric materials far superior to that available in the past, attempts have been made to convert the heat from solar radiation directly into dc electric power by means of thermopiles located at the foci of parabolic mirrors. Results have been encouraging, but both the size and efficiency of the units have been small.<sup>5, 7</sup>

The conversion device here presented is a composite of two separate portions of a solar converter. The mechanical converter was set up and tested in the authors' basement shop. The performance curve of a thermopile is shown to illustrate a typical design condition in matching thermopile to mechanical converter.

## THE THERMOELECTRIC PILE

The thermoelectric element necessary for the first stage of the solar converter can be designed from experience gained from small thermopiles using presently available materials. The physical properties of very good thermal materials for this purpose are presented in the Patents No. 2,811,440 and No. 2,811,571 issued to R. W. Fritts. Although the material described can be operated at 565°C for short periods under conditions that prevent oxidation, it is considered desirable to limit the temperature of the hot junction to 450°C. Other materials observed have similar limitations.

It is desirable to operate a thermopile at its maximum temperature differential between hot junction and cold junction to get maximum power output and efficiency, as illustrated in Fig. 4. This means keeping the cold junction as cold as possible. With the condition imposed that heat rejected from the thermopile must operate the mechanical converter, this cold junction temperature must be of the order of 60°C.

## THE SOLAR COLLECTOR

The solar collector must satisfy the following conditions:

- (1) Adequate effective area of collection.

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FIG. 1

(2) Sufficient concentration to produce the level of temperature required at the hot junctions under load conditions.  
 (3) Approximately uniform collection during the day.

Research has shown that a parabolic cylindrical collector with the thermal elements at the focus will give sufficient concentration to maintain 320°C temperature at the hot junction of a thermopile placed at the focus.<sup>9</sup> Approximately uniform collection during the day can be achieved by placing the collector on pivots such that the axis of the collector and the pivots are mutually along a north and south axis.

#### THE MECHANICAL CONVERTER

The mechanical converter, hereafter referred to as a "transthermer," is shown in Fig. 1. It is an open cycle heat engine using air and water vapor as the working substance. It can work efficiently from heat discharged from a thermoelectric converter at 60°C. Thus this heat engine can act as the heat sump for the thermoelectric converter. Whereas the temperature differential of the thermocouple should be 400°C for efficiency, the temperature differential of the transthermer needs to be only 20°C, as shown by the thermodynamic diagram of Fig. 3. The ambient air condition is taken to be that of arid regions where the relative humidity is 20 per cent or lower and the dry bulb temperature is 25°C or above.

The immediate question may arise why the conversion efficiency of the mechanical converter is greater than that of the thermoelectric pile while its temperature differential is only one-twentieth that of the

thermoelectric part, as is shown in the temperature-entropy diagram of Fig. 3. The answer lies in the fact that the entropy of dry air and separate water vapor at pressure  $P_1$  is less than the entropy of the same air with the water vapor diffused in it to a pressure  $P_2$ .

The change of entropy is:

$$S = nR \ln \frac{P_1}{P_2}$$

where  $n$  is the number of moles of water evaporated. This means that free energy is available by evaporating water vapor into air having a low relative humidity. The theoretical power available is given by:

$$W_o = W_i \frac{TR}{H_v} \ln \frac{1}{r} \quad \text{or} \quad \eta = \frac{W_o}{W_i} = \frac{TR}{H_v} \ln \frac{1}{r}$$

where:

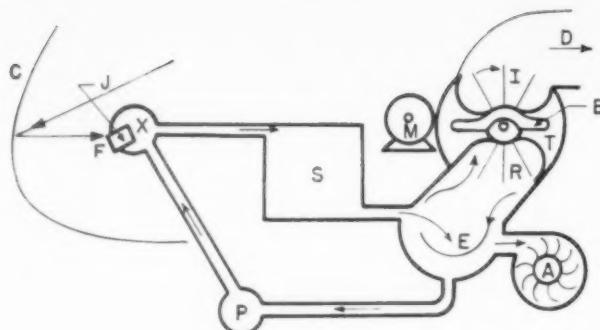
$W_i$  is the power equivalent of the heat flow to the evaporator,  
 $T$  is the absolute temperature at which evaporation takes place,  
 $R$  is the gas constant,  
 $r$  is the relative humidity of the air after evaporating water into it,  
 $H_v$  is the heat of vaporization,  
 $\eta$  is the theoretical isothermal efficiency.

Given relative humidity of 20 per cent at temperature 340°K (67°C) the theoretical efficiency is 13.5 per cent. Each pound of water evaporated has the potential of lifting a pound 117,000 ft. Intrinsic adiabatic inefficiency of the cycle cuts these values to half. Actual efficiency is near four per cent.

The mechanical converter evaporates water in the lower tank portion, shown in Fig. 1. This evaporation takes place at a pressure of but two or three pounds per square inch and over a large surface in contact with air. This eliminates the problems of sediment and boiler scale that are encountered with normal steam engines. It also means that the water need not be fresh, but may be salty. The magnitude of power involved means that necessary water can be pumped to a considerable elevation or may be syphoned for considerable distances.

#### ENERGY STORAGE

An intrinsic deficiency of solar converters of the thermoelectric or photoelectric type is that they produce no power during darkness or even cloudy weather. This same deficiency also applies to a less degree to solar collector and steam engine combinations, because water several degrees above the boiling point loses heat so rapidly that heat storage is impractical. Considerable research has been done by other observers on heat losses in collectors at temperatures up to 200°F above ambient.<sup>4</sup> Heat storage at 200°F



COMPLETE SOLAR CONVERTER  
FIG. 2

(93°C) above ambient is not efficient enough to be useful for a thermoelectric converter, as is shown by Fig. 4. Storage of heat by materials with fusion points in the temperature range required by thermoelectric hot junctions becomes costly and inefficient.

The picture is much brighter for the storage of heat for operating the "transthermer." The requirement here is merely for water at a temperature to produce 90 cm or more of vapor pressure. This is attained at 50°C, which may be only a few degrees above ambient.

Heat storage for greater periods than a few hours seems impractical. Solar energy converters should be tied into a power network including hydroelectric storage for long period power equalization. The ocean can be employed for hydroelectric storage.

No actual tests have been made on the storage of heat for this heat engine. But assuming a thermal conversion efficiency of 4 per cent, with heat loss of 20 per cent, and a total temperature depression of 20°C, it would require 765 cu ft of heated water to deliver one kilowatt for sixteen hours, or 765 cu ft at 1000 ft elevation.

The thermoelectric converter associated with the mechanical converter would have its greatest usefulness as a means for starting the accessory equipment such as pumps and blower, and as a peaking power source in areas where power demands for industry, irrigation, and air conditioning are likely to be the greatest during the middle of the day. The absence of moving parts in the thermopile makes it highly reliable; this converter can carry emergency load during service shutdown for the mechanical converter.

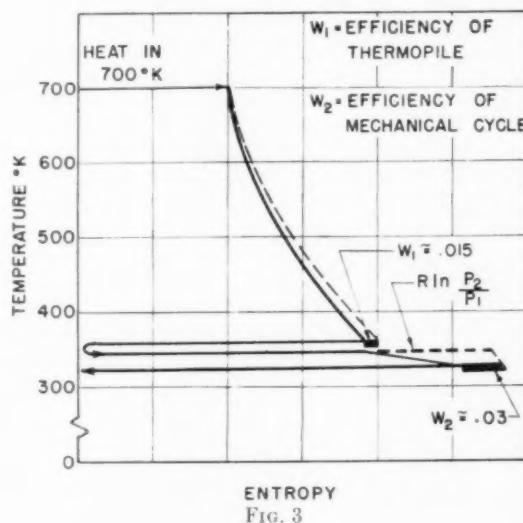
#### THE COMPLETE CYCLE OF OPERATION

The complete solar converter is illustrated in Fig. 2. Solar radiation falls on the parabolic collector, C, and is concentrated at the hot junctions of the thermopile, J, which is located at the focus, F. All the thermoelements are connected in electrical series, so there is alternately a hot junction and a cold junction. The heat flows away from the hot junction through both con-

nected elements, while the current enters by one junction and leaves by the other. Thus heat flows with the current in one element and counter to the current in the other element. Therefore the elements must be of two kinds of material having opposite thermoelectric properties. They are designated respectively as "p" material and "n" material. Electrical and thermal conductivity of both materials increase as temperature increases. This property permits heat to flow through the converter more rapidly when heat is supplied at a greater rate, which helps prevent the temperature from rising so high at the hot junction as to fuse the material.

Water is circulated through the heat exchanger, X, surrounding the cold junctions of the thermoelements by pump, P. Thus water acts as a heat sump for the thermoelectric generator and as a heat storage medium at S. It then carries heat to the hermetic enclosure of the "transthermer," E, where it is used to produce

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ENTROPY  
FIG. 3

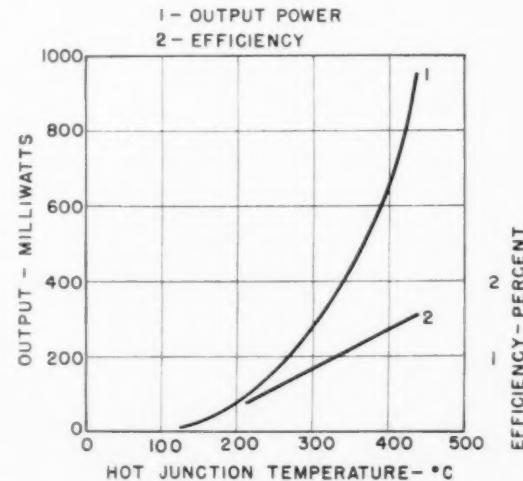


FIG. 4

evaporation at a gage pressure of 1-5 psi. A large evaporating surface is provided in *E* to speed evaporation. The surplus water returns to pump. Air flow is from 675 to 1080 cu ft per minute. It requires only a  $\frac{1}{2}$ -hp motor to overcome bearing friction and the dynamic reaction of the circulated air.

Pressure is built up in the evaporator by the added partial pressure of the water vapor. This pressure becomes usable to drive an air turbine *A* at temperatures above 120°F (49°C). At this temperature the added pressure becomes 1.69 psi, which represents one tenth of the total volume. Thus, if there are no volume losses, 67.5 to 108 cu ft of moist air per minute at 1.69 psi pressure could be delivered to the air turbine with 0.5 indicated horsepower. The machine would need to be very efficient to operate at this condition. But the gross indicated power rises nearly as the square of the vapor pressure, which nearly doubles with each 16°C rise in temperature. Thus at 60°C the vapor pressure is 2.89 psi, which represents 19 per cent of the original volume. This permits 190 cu ft of air per minute to be delivered to the air turbine at a gage pressure of 2.89 psi. This indicated power is 2.4 hp or 2 kw. Again, the actual power depends largely on the amount of leakage between the edges of the rotor vanes and the housing.

The function of the pressure inverter tube, *B*, is to conserve the pressure in evaporator so it can accumulate to gage value considerably in excess of the water vapor pressure. This can be done because of Dalton's principle, which allows vapor pressure to add to any previously provided air pressure. Therefore the dry air should be compressed before vapor is added to it. The pressure inverter tube acts similar to turbine and compressor combination to maintain an elevated pressure in the combustion (expansion) chamber of a gas turbine jet engine. As the pressure inverter tube comes in communication with the moving intervane spaces with pressure greater in the one at the left end than the one at the right end, air surges from the left to the right. Momentum and kinetic energy in the mass of air in tube, *B*, causes it to pass equilibrium condition and reverse the pressure condition in the vane enclosed compartments at the left of the rotor and at the right of the rotor. Thus compressed air does not leave at the discharge, and energy of compression is not lost. Instead, the energy is used in compressing air before it enters the evaporator. This permits gage pressure to be maintained in the evaporator considerably above the vapor pressure.

Leakage is reduced by designing the vanes with double seal edges which act as a crude labyrinth seal. Labyrinth seals are used at each end of the hub. Actual friction exists only in the ball bearings.

The pressure inverter tube must have a volume at least 0.025 the volume enclosed between adjacent

vanes in order that the peak kinetic energy of the enclosed mass of air can be sufficient without attaining velocity higher than approximately 0.6 the speed of sound. Energy losses in air passages become very great at speeds approaching that of sound. It is also necessary to have the passage of sufficient cross-section that air pressure reversal in the vane enclosed spaces can take place in slightly less than one hundredth of a second.

## RESULTS AND CONCLUSIONS

Over-all thermoelectric efficiency is low (1.5 per cent), but more efficient materials are being developed that may yield 5 per cent efficiency. Good thermoelectric materials are new and as yet quite expensive. But it is felt that this is no hindrance to the use of thermoelectric converters because the weight of material used need not be large. The weight of material used in any design can be reduced by 75 per cent by simply cutting the length in half. This in turn reduces the necessary cross-section to half, for the resistance to the flow of heat follows the same law as resistance to flow of an electric current. It is expected that greater use of thermoelectric materials will reduce the cost. There is also steady progress in the production of materials that will operate at higher temperature. All heat lost from the thermoelectric converter can be applied to the mechanical converter. The solar collector need be no larger to serve both thermoelectric and mechanical converters in sequence than to serve one converter alone. The usable life of thermoelectric materials should be indefinite, but research has not determined what limitations there may be. There are technical problems in making good electrical connections with thermoelectric material.

The collector is likely to give the greatest maintenance problem, as the specular reflectivity of the surface must be kept quite high. Dust will tend to collect on all surfaces that are not oriented at a steep angle. Also wind-blown dust will probably present an erosion problem. The thermopile must be operated at optimum temperature, so it demands that a simple tracking mechanism be employed to keep the collector oriented toward the sun during the day. Unless the collecting system and thermopile are each of high quality the value of the thermopile is marginal. If the transthermer alone is used, a fixed solar collector is adequate.

It is found practical to build the rotor of the mechanical converter such that the clearance between the rotor vanes and the housing is but 0.004 in., if it is made of steel. This limits leakage to 60 cu ft per minute. It is found that aluminum has too great thermal expansion to achieve these limits. Tests indicate necessary clearance of 0.008 in. when rotor and shell are made

of aluminum. Leakage increases at a rate which is near the second power of the clearance value when of this order.

With inverter tube well streamlined, it is found that pressure conservation is good. The energy losses due to allowing moist air to leave in an unexpanded condition can be kept to a much smaller value than energy losses due to leakage. The inverter tube recovered 75 per cent of the dynamic volume loss.

The mechanical converter should operate at a temperature to give 4 per cent efficiency. This requires 2-5 psi pressure in the evaporator. Higher pressure in the evaporator can raise the efficiency to 6 per cent. This may give an over-all efficiency of 10 per cent in combination with newly developed thermoelements. The solar energy input needed for a 2-kw converter at 4

per cent efficiency is 50 kw. Assuming collector efficiency of 50 per cent, 1,250 sq ft of solar radiation must be intercepted.

#### REFERENCES

1. *The Sun at Work* 3 (1), Mar. 1958
2. *The Sun at Work* 3 (2), June 1958
3. *Solar Energy; the Journal of Solar Energy, Science and Engineering*, 2 (1), Jan. 1958
4. J. I. Yellott, "Power from solar energy." *Trans. ASME*, 79 (6), Aug. 1957
5. R. W. Fritts et al, "Thermoelectric converters." *U. S. Patent No. 2,811,571*
6. John Ericsson, "The sun motor." *Nature*, 31: 10, Jan. 1887
7. A. F. Ioffe, "Semiconductor thermoelements and thermoelectric cooling." English Translation, USSR Academy of Sciences.
8. T. C. Holmes, "Thermoelectric generation of power." *J. App. Phys.* 29: 1471, Oct. 1958
9. N. F. Shuh and R. J. Tallent, "Solar-powered thermoelectric generator design considerations." AIEE Technical Paper, June 1959.

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# Solarization Studies on Polyester Resins Using a Heliostat-Spectrometer

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**Natural sunlight has the photochemical effect referred to as "solarization" on polyester resins, producing yellowing as well as causing undesirable changes in other physical properties. The question of what wavelengths in the ultraviolet portion of the solar spectrum are responsible for the solarization has gone unanswered for lack of experimental data. It was decided to study the solarization of polyester resins using natural sunlight and to measure the conditions as closely as possible during exposures.**

A heliostat was constructed to send a beam of sunlight into a fast optical system consisting of a concave mirror and a quartz prism monochromator. The ultraviolet portion of the solar spectrum was spread across the resin sample which was in the focal plane of the spectrometer. The "activation spectrum" is the degree of yellowing as a function of incident wavelength as determined by densitometry of the resin sample with monochromatic blue light.

Polyester resins which were cross-linked with polystyrene were studied. The dibasic acids present were varied among phthalic plus maleic, adipic plus maleic, succinic plus maleic, and all maleic. Virtually identical activation spectra were obtained for the formulations, with maxima near 3300 Å.

Plots of yellowing versus the logarithm of the exposure gave straight lines, showing that, for monochromatic light, the resins obeyed the classic Hurter-Driffield law of photographic materials. Inertias and slopes were nearly the same for all formulations.

In cases where the samples were solarized at very high rates, a dark reaction was observed following exposure which caused a fading of the yellowing. This may be interpreted as the destruction by oxygen of trapped free radicals.

## INTRODUCTION

Sunlight has the photochemical effect on polyester

resins of producing yellowing. This is referred to as "solarization." Additional undesirable changes may take place in other physical properties. The question of what wavelength regions in the ultraviolet portion of the solar spectrum are responsible for the solarization has gone unanswered for lack of experimental data. In addition, correlations between outdoor and indoor exposure tests frequently fail, due both to the fact that outdoor conditions are not standardized and that the various indoor sources have widely differing spectral energy distributions and do not duplicate natural sunlight.<sup>1</sup> Hence it was decided to study the solarization of polyester resins using natural sunlight and to measure the conditions as closely as possible during exposures.

A heliostat was constructed to send a steady beam of sunlight into a fast optical system consisting of a concave mirror to concentrate the beam and a fast spectrometer. The ultraviolet portion of the sunlight was spread out across the polyester sample in exactly the same manner as if it were a photographic plate in a conventional spectrograph. Densitometry of the samples was also done as though they were photographic plates, but using monochromatic blue light. Plots of the extent of yellowing versus wavelength of the incident light produce an "activation spectrum." Rates of yellowing are obtained from plots of extent of yellowing versus exposure, or total energy received. A considerable degree of acceleration was obtained.

## APPARATUS

The heliostat unit proper consisted of a 12-in. square, front-surface aluminized mirror which was mounted to rotate about an axis parallel to the axis of rotation of the earth, driven by a synchronous motor and reducing gears. The beam from the rotating mirror was sent down the axis of rotation to strike a similar mirror, which reflected the beam vertically downwards into the building below. The optical system is shown diagrammatically in Fig. 1, and the external heliostat is shown in Fig. 2. Fig. 3 shows the indoor optical and electrical components.

A 12-in. square mirror inclined at 45° to the horizontal reflects the beam to the concave mirror which

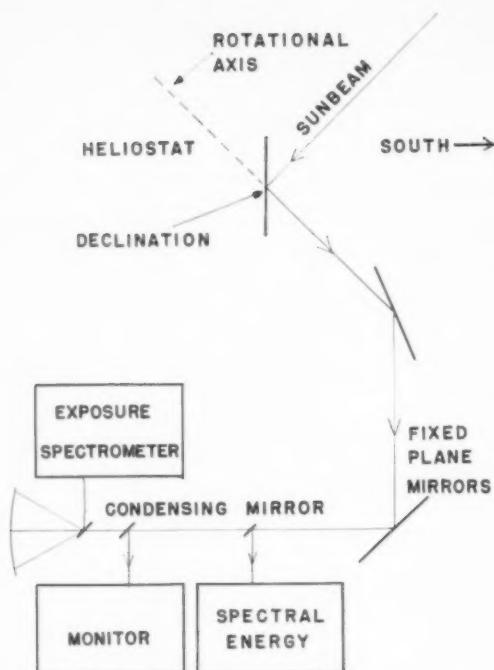


FIG. 1—Schematic diagram of heliostat-spectrometer components.



FIG. 2—View of heliostat and protective housing.

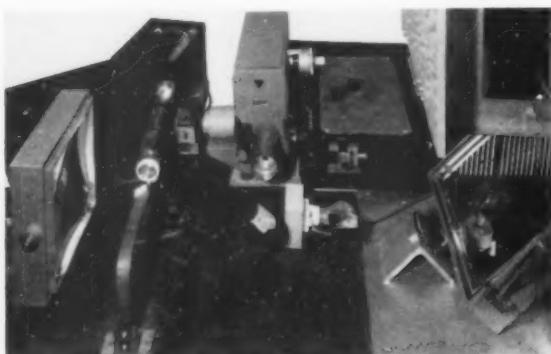


FIG. 3—Indoor optical components, showing photochemical spectral distribution, and monitoring monochromators.

focuses it just after reflection from the small mirror mounted in Newtonian fashion. An f/1.25 quartz lens (which is over-filled by the beam from the concave mirror) renders the concentrated sunbeam parallel, and a second quartz lens focuses it on the slit of the photochemical spectrometer. The optical path of this spectrometer includes two large quartz 30° prisms, which are the limiting apertures of the system, giving it a speed of f/2. The entrance slit is imaged on the plastic sample which is fastened in the focal plane at the exit slit of the spectrometer.

The image of the sun on the entrance slit is 2 mm in diameter, and the slit is 0.5 mm wide. About one-third the power in the image is admitted to the spectrometer. The system is focused for the 2900 to 4000 Å region, so the visible and near infrared regions are somewhat out of focus at the entrance slit. These portions of the spectrum are ultimately reflected onto and absorbed by the interior wall of the spectrometer in a highly dispersed condition to avoid the overheating of the exit area of the instrument. The installation was made in a building located north of the main laboratory in Stamford, Connecticut, having a location of 41°03'04" north latitude and 73°33'45" west longitude.

To protect the outdoor optical and electrical components from the weather, a mobile housing was provided which operated on rails. This cover was rolled to the open position by a motor and cable arrangement, and held open by a magnetic clutch. Closing was effected by a heavy counter weight released by the clutch. The unit was designed to operate without supervision except for start-up in the mornings and occasional checks during exposures. The cover was closed by a timer about 5 p.m., or by a rain-sensitive element, or by semi-darkness due to clouds. The latter was effected by a photocell viewing the sky through a hemispherical diffusing globe, which released the counter-weight clutch when the sky became darkened with clouds. The mirror was operated in reverse during the night by use of limit switches, so that the same gear teeth were engaged at the same hour each day.

No automatic corrective devices were used for "tracking" the sun. The altitude and azimuth adjustment screws used produced reasonably good tracking, but operated a little "fast." An electrical timer made periodic halts of a few seconds during the day to bring the image into proper register; this was determined empirically. The change in declination was adjusted manually each day.

The extent of exposure was monitored by diverting a small pencil of light into a second spectrometer, referred to as the monitoring spectrometer. This consisted of a slit, a 60° quartz prism with a Littrow mirror, and a phototube. The latter was permitted to receive, by use of baffles, exactly the same ultraviolet

wavelengths as struck the exposed plastic sample. The photocell signal was amplified and presented on a Micromax recorder. A gear on the slidewire of the recorder turned a 10-turn helipot, which regulated the voltage from a battery to a small, low-inertia motor driving a counter. This integrated the intensity of the sunbeam with time, and compensated for occasional clouds, haziness, etc. A ferri-oxalate actinometer<sup>2</sup> was used behind the photochemical spectrometer to calibrate the integrator's counter units in terms of joules (watt-seconds). All exposures were expressed in joules rather than in units of time.

A third spectrometer is also shown in Fig. 3. This is a Bausch and Lomb grating monochromator, fitted with a quartz lens to focus the incident sunbeam onto its entrance slit. A photomultiplier, feeding into a Photovolt-type 520-A amplifier and meter, was rigidly mounted beyond the exit slit of the monochromator, and was calibrated with the ferri-oxalate actinometer. The wavelength drum was turned manually during the taking of the spectral energy distribution data, using a standard form for recording the data. This was the same unit as was used for the comparison of the spectral energy distributions of indoor test light sources, described elsewhere.<sup>1</sup> Energy was expressed in microwatts per sq cm per 30-A band.

A microphotometer, or densitometer, of the Knorr-Albers type was modified to operate with monochromatic light. An 85-watt type AH3 mercury lamp and filters were used to isolate the 4358 Å line of mercury. The red-sensitive phototube was replaced with a blue-sensitive tube. The solarized portions of the polyester samples, being yellow, absorbed blue light.

## DATA AND DISCUSSION

During 1956 and 1957, polyester formulations cross-linked with polystyrene were studied. The dibasic acids present were phthalic and maleic, adipic and maleic, succinic and maleic, and all-maleic. The dihydric alcohol used was propylene glycol. The formulations included 30 per cent styrene for cross-linking. In addition, phthalic-maleic-propylene glycol and styrene formulations in which the alkyl-to-styrene ratio was varied were studied.

The activation spectrum is the extent of yellowing versus the wavelength of the incident light, and arises from a function of the absorption spectrum of the photosensitive entity or entities, their quantum yields, and the spectral energy distribution of the source. Virtually identical activation spectra were obtained for all the formulations, stretching from the lower limit of natural sunlight near 2900 Å to about 3500 Å, with the maxima generally in the vicinity of 3250 to 3300 Å.

Plots of yellowing (measured by the absorbance at 4358 Å) at the maxima of the activation spectra versus

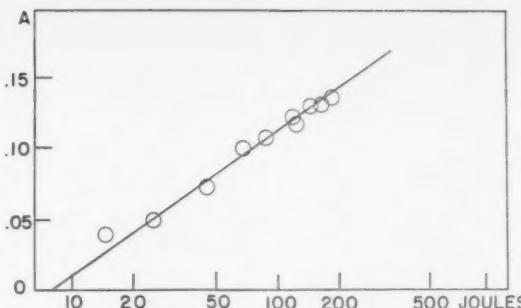


FIG. 4—Plot of yellowing (measured as absorbance at 4358 Å) versus exposure in joules for the succinic-maleic polyester formulation.

the exposure (in joules) gave curves. Plots of yellowing versus the logarithm of the exposure gave straight lines. This shows that for monochromatic excitation the polyesters obeyed the classic Hurter-Drifford law of photographic materials. The slope of the yellowing vs. log exposure curve, known as "gamma" or "photographic contrast," was virtually the same for all formulations. The inertia values were likewise very nearly the same. The equation of the Hurter-Drifford law<sup>3</sup> is:

$$A = \gamma (\log E - \log i)$$

where:

$A$  is the absorbance or optical density,

$\gamma$  is the slope, or contrast,

$E$  is the exposure, or product of intensity and time, measured in joules (1 joule =  $10^7$  ergs = 1 watt-second),

$i$  is the inertia, in joules.

The data for the inertia and contrasts of the various formulations are summarized in Table I and shown for the succinic-maleic samples in Fig. 4.

TABLE I  
RATE OF YELLOWING OF POLYESTER FORMULATIONS

Formulation type	Alkyd/styrene ratio	Inertia (in joules)	Contrast, or rate of yellowing, (in absorbance/ $\log$ exposure)
Adipic/maleic.....	70/30	9	0.10
Phthalic/maleic.....	70/30	11	0.11
All-maleic.....	70/30	14	0.13
Succinic/maleic.....	70/30	8	0.10
Phthalic/maleic.....	85/15	20	0.10
Phthalic/maleic.....	70/30	17	0.09
Phthalic/maleic.....	40/60	17	0.09
Phthalic/maleic.....	25/75	13	0.11

From the similarity of the activation spectra and the values for contrast and inertia, it appears that the yellowing or solarization phenomena are associated with photosensitive entities common to all formulations. This may be associated with the cross-linking polystyrene or due to isolated absorbing centers such

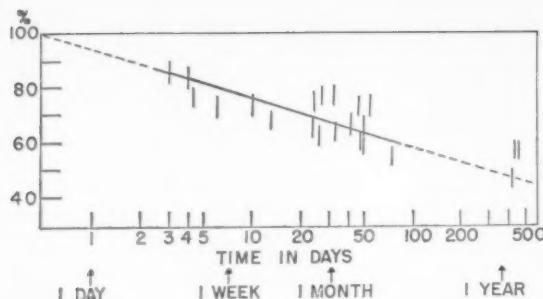


FIG. 5—Plot of per cent yellowing remaining versus time (on a logarithmic scale) at room temperature (phthalic-maleic formulation).

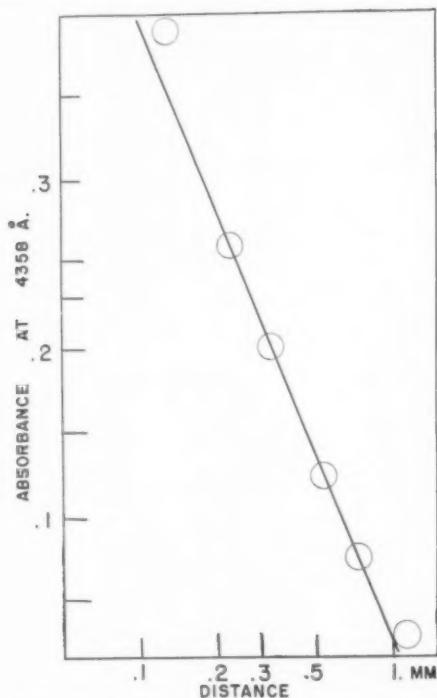


FIG. 6—Penetration of yellowing: absorbance at 4358 Å versus distance from solarized surface.

as carbonyl (ketone) groups. The latter is considered the more likely explanation.

A dark reaction, which consisted of a fading of the yellowing, was observed. This effect is quite opposite to the continued yellowing in the dark found by other investigators,<sup>4</sup> using polychromatic excitation. The fading of the yellowing was followed with time, and found to be logarithmic with time, as shown in Fig. 5.

It appears that two types of yellowing are involved, one a permanent yellowing and the other a transient. If samples are yellowed at low rates, the fading or dark reaction may not be observed, since the observed yellowing rate is really the resultant of the permanent yellowing rate and the transient yellowing which has nearly completely faded back. At the high rates of

yellowing obtained from the heliostat-spectrometer unit, where perceptible yellow may be found within two hours with 20 to 40 joules, the dark reaction is noticeable. Refrigeration to 0°C slowed the fading rate by approximately one-half.

An explanation of the fading phenomenon is that the yellowed centers are quite reactive (possible trapped free radicals) and they are destroyed by the penetration of oxygen into the plastic.

An attempt was made to calculate an activation spectrum by multiplying the spectral distribution of sunlight in the ultraviolet<sup>1</sup> by the observed absorption spectrum of the unexposed plastic samples, wavelength band by wavelength band. These calculated activation spectra did not show maxima near 3250 Å, however, but continued upwards to the limit of terrestrial sunlight. This is interpreted as showing that the photo-sensitive entity (or entities) do not have the same absorption spectrum as the total formulation, but rise at a much slower rate toward short wavelengths. This further strengthens the isolated ketone group explanation.

During the course of the exposure work, it was desired to examine the penetration of the yellowing through the sample. A yellowed sample was cut in two, and the pieces turned 90° toward each other, so that the yellowed surfaces were in contact. The sample was densitometered in this position, producing a curve that rose to a maximum at the point of contact and fell again across the second piece. The values were plotted, as in Fig. 6, to show that the yellowing varies inversely with the logarithm of the distance from the exposed face, as would be predicted from the absorption law (Beer's Law).

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#### REFERENCES

1. R. C. Hirt; R. G. Schmitt; N. D. Searle; A. P. Sullivan. Paper No. SB45, presented before the Optical Society of America, at Detroit, Michigan, Oct. 11, 1958; abstract in *J. Opt. Soc. Amer.* **48**: 873, 1958.
2. C. G. Hatchard; C. A. Parker. *Proc. Roy. Soc. (Lon.) A-220*: 104-16, 1953 and *A-235*: 518-36, 1955.
3. N. H. Nachtrieb, *Spectrochemical Analysis*. N. Y., McGraw-Hill, 1950, p. 104-5.
4. M. J. Reiney; M. Tryon; B. G. Achhammer. *J. Res. Natl. Bur. Stds.* **51**: 155, 1953. L. A. Wall; M. Tryon. *Nature* **178**: 101, 1956.

# Mankind, Civilization, and Prosperity

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Mankind is exhausting his sources of energy at an alarming rate. Within about 50 years oil supplies will be exhausted, and the coal will not last longer than 90 years. Even atomic energy, of which so much is expected, can provide us with energy only for a couple of centuries if the present increase in consumption continues. Therefore, it is of vital importance to stimulate the utilization of energy from natural sources such as solar radiation, wind power, and hydro power.

It is not easy to give a definition of "civilization," because every man defines it by his own standards, dependent upon the milieu in which he is living. When we consider exclusively the Western World, that is, a world in which only 25 per cent of the total population of our earth is living, then the generally accepted standard states that the level of civilization is defined by the *use of energy* by the people. It is tacitly accepted that civilization goes together with prosperity.

Perhaps it would be more realistic not to speak about civilization at all, but to put the accent more on prosperity, which directly implies the use of energy.

We can distinguish several different kinds of energy. For convenience sake we shall express the quantities of energy in a unit Q first used by Putnam<sup>1</sup> in the United States and defined as the energy equivalent to  $0.25 \times 10^{18}$  kcal, or  $30 \times 10^9$  tons of charcoal. The principal kinds of energy are:

## (1) Energy of the Sun

On the average, this energy amounts to 2300 Q per year, divided over the earth as in Fig. 1.

## (2) "Inspired" Energy

This energy is fixed in plant material by the photosynthesis of carbon dioxide and water under the influence of sunlight catalyzed by chlorophyll, enzymes, and salts:



The reaction is endothermic and takes place at rather low temperatures. The required energy is delivered by a part of the radiant energy of the sun, viz., the spectrum range 0.6–0.7  $\mu$ . The reaction in the reverse

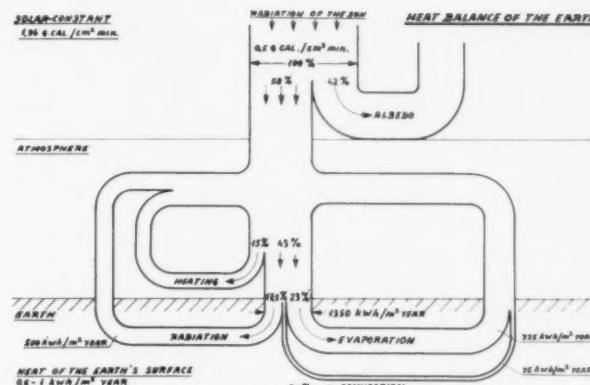


FIG. 1—Heat balance of the earth.

direction represents respiration, in which carbohydrates are oxidized to carbon dioxide and water by oxygen from the air at temperatures of 30–40°C. Both reactions, photosynthesis and respiration, take place only in the *living* organism.

The quantity of inspired energy on earth is limited by the net output of photosynthesis. Considering that only one-fourth of the sun's energy, viz., 600 Q per year, is falling on land, and that from the point of view of climatological factors and soil structure about 40 per cent of this surface is suitable for photosynthesis, then only 240 Q per year is available. The maximum output of photosynthesis amounts to 0.5 per cent. Using an average of 0.1 per cent, we get an amount of 0.24 Q per year inspired energy which is really available. The total quantity of energy that mankind consumes nowadays is 0.1 Q per year.

## (3) Stock Energy

This form of energy is present in the reserves of fossil fuel (oil and coal) which has been conserved by the earth over about 300 million years. The reserve nowadays is valued at 25 Q for oil and 150 Q for coal. These figures represent the known as well as the estimated reserve. In reality we have to calculate with one-third of these quantities.

## (4) Atomic Energy

Atomic energy can be divided into:

- energy from the disintegration of the elements uranium and thorium,

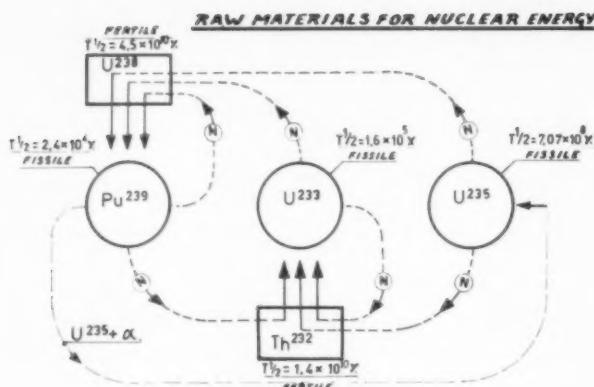


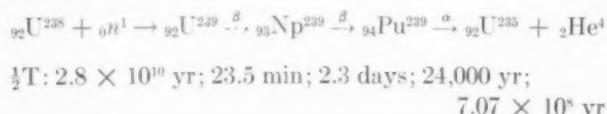
FIG. 2—Raw materials for nuclear energy.

(b) energy from the fusion of the element deuterium, i.e., the heavy isotope of the element hydrogen called *heavy hydrogen*.

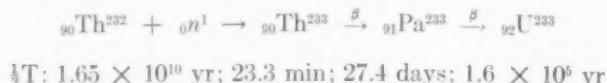
As to the available quantities, we shall again use the highest valuation for the known and estimated quantities of uranium and thorium present in the earth.

For uranium and thorium this quantity amounts to 1800 Q. Starting with a disintegration energy of one ton U 235 equivalent to  $2 \times 10^{13}$  kcal or with  $2.5 \times 10^6$  ton coal of 8000 kcal per kg, we calculate a world stock equivalent to 22.5 million tons U 235. This quantity consists of 99.3 per cent of U 238 that is not fissionable; the rest, or 0.7 per cent, consists of U 235, an isotope of the element uranium that is fissionable. Using natural uranium, only  $1\frac{1}{4}$  per cent of the above-mentioned 1800 Q, i.e., about 13 Q, would be available. Fortunately it is possible to convert the U 238 by breeding into plutonium, which is fissionable like U 235.

Because of the rather short half-life of the intermediate products, it is possible to convert the U 238 by a capture of slow thermal neutrons (with an energy of about 0.5 ev per neutron at 300°C) into plutonium, with a half-life of about 24,000 years. Moreover, the plutonium disintegrates slowly into U 235. The mechanism of these reactions is presented by the following scheme (Fig. 2).



Another element from which we may obtain fissionable energy is thorium. This element is present in the earth's crust only in small amounts, and like U 238 it is not directly fissionable. In the same way, it can be converted into U 233 by neutron capture as follows:



Theoretically, therefore, the elements U and Th can be completely used. Up to now techniques have not been developed to the point that the breeding processes can be realized on a large scale, and even when this is achieved we will have to calculate with an efficiency of conversion of far less than 100 per cent. If we consider that of the 1800 Q only one-third, or 600 Q, will be available as useful energy we are still being very optimistic.

Deuterium fusion reactions have already been applied in the hydrogen bombs, where the fusion reaction proceeds in an uncontrolled fashion at about 20 million degrees C. It is under these conditions that the sun produces atomic energy from hydrogen.

The most simple fusion reaction is:



The production of energy per ton D<sub>2</sub> equals that of 1 ton U 235. When we consider the sea as possible source of D<sub>2</sub>, it can be calculated that, with a D<sub>2</sub>O content of 0.015 per cent, the total amount of D<sub>2</sub>O is about  $210 \times 10^{12}$  tons or  $40 \times 10^{12}$  tons of D<sub>2</sub>. This is equivalent to  $100 \times 10^{18}$  tons of coal or  $3 \times 10^9$  Q. If we assume that only one-third can be recovered and that, moreover, the efficiency of conversion is 100 per cent, then the available energy from D<sub>2</sub> is only  $10^9$  Q.

Summarizing, we can give the following very optimistic statement of the reserves of energy:

petroleum.....	8.7 Q
Oil oil shale and sands.....	8.7 Q
gas (natural).....	5.6 Q
	23.0 Q (stated as 25 Q)
Coal.....	150 Q
U + Th.....	1800 Q
Deuterium.....	$3 \times 10^9$ Q

Of these stocks only one-third may be considered as real.

## HOW LONG WILL ATOMIC ENERGY AND STOCK ENERGY LAST?

To answer this question we have to know the consumption of unspent energy by mankind. According to Putnam, mankind used about 9 Q up to 1850, and from 1850-1950, 4 Q. Furthermore, it appears that by dividing the past century (1850-1950) into periods of 10 years, the increase of the energy consumption amounts to 4-4.6 per cent per year. (The periods of war are not included.) If, for the next 25 years, we count on an increase of 4 per cent per year, the total consumption at the end of this period will be 4.5 Q, at a commencing expenditure of 0.1 Q in 1958.<sup>2</sup> (The figure 0.1 Q is rounded off. In reality it is 6 per cent more, i.e., 0.106 Q.)

The specification of the world expenditure in 1958 is as follows:

Energy	Q	Per cent
Oil.....	0.040	37
Natural gas.....	0.013	12
Coal.....	0.053	49
Water power.....	0.002	2
Non-commercial fuel.....	0.108	100
	0.012	

Exclusive of water power, the consumption is 0.106 Q, rounded off to 0.1 Q.

Fig. 3 represents the *cumulative* consumption based on the formula

$$Q = Q_0 \frac{1.0p^{(n+1)} - 1}{1.0p - 1}$$

where:

$Q_0$  = commencing consumption, here 0.1 Q,

$p$  = per cent increase per year,

$n$  = number of years.

Besides the curve for an increase of 4 per cent per year, we have calculated the curve for an increase of 1 per cent per year. The ordinate gives the number of years; the abscissa at the top of the figure shows the total Q values and at the bottom the one-third Q values.

Using the one-third Q values we can see that the reserves of oil and coal will be used with an increase of 1 per cent per year after about 200 years and with an increase of 4 per cent per year after 80 years. Taking the quantities of oil and coal on an equal basis (this situation existed before 1958), then the oil will be used up after 90 years with 1 per cent increase per year, or after 50 years with 4 per cent, i.e., in about the year 2010. Nuclear energy will last just a little longer, but after a rather short time this energy, too, will be exhausted. Then the last source will be deuterium, if, in the meantime, we succeed in converting this material into usable energy. For the time being it is wise not to expect too much of it, especially when we consider that the expectations today are that in 25 years

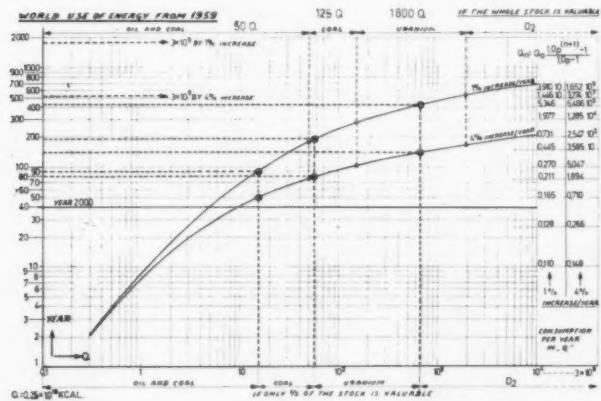


FIG. 3—World use of energy from 1959.

only 10 per cent of the energy needs can be covered by nuclear energy. Therefore, development in this field must continue at a quicker rate.

The total quantity of uranium and thorium will be sufficient for only 150 years (with an increase of 4 per cent per year). Including the D-energy, all the presently available sources of energy will be exhausted in 560 years. Our calculations are optimistic; the real picture is worse.

### WHAT IS THE FUTURE OF MANKIND?

This question involves the following problems:

- What form of energy can we use when the whole stock of raw material for the production of energy is exhausted?
- What is the situation in connection with the food supply and the increase of the world population?
- What is the meaning of technology in this future?

An increase in the consumption of energy of 4 per cent per year means that within 100 years the reserves of oil and coal will be exhausted. Continuing with the exploitation of uranium, even if deuterium proves usable, will produce a gigantic scar in the earth's crust within only a couple of centuries, and posterity will have to face the disastrous consequences. The only form of energy mankind will have at his disposal, then, is the energy of the sun.

We can distinguish between the energy of heat radiation and of light radiation. In addition, we are familiar with derived solar energy, i.e., wind and water power, undulation, geothermal energy, and the tides. Before mankind has to live by the sun's energy alone, there will be a period in which the element carbon will be exhausted as fuel and also as raw material for chemical and metallurgical purposes. The energy from the burning of carbon can be replaced by atomic energy. However, nuclear energy cannot replace carbon for industrial purposes, unless it can be used to extract carbon from the large available quantities of limestone. In this respect, it is interesting to know that the quantity of carbon in the sedimental limestone formations amounts to about  $0.1 \times 10^{17}$  tons.<sup>7</sup> Transformed into a combustible state, this means a profit of  $3 \times 10^5$  Q, i.e., 2,000 times the energy fixed in the present quantities of coal (150 Q).

Long before the above-mentioned process can be realized, the difficulty of keeping the gasoline engines going will arise, because, at least in automobiles, these cannot be replaced by nuclear engines. The raw materials suitable for this purpose are wood and the fermentation products of carbohydrates, both of which are photosynthetic products and therefore in limited quantity.

According to recent statements of the Food and

Agricultural Organizations of the United Nations (F.A.O.), the total surface covered with forests on the earth amounts to  $4 \times 10^7$  sq km, i.e., about 30 per cent of the total land surface. Of this forest surface, only 35 per cent is remunerative, 30 per cent is not (yet?) accessible, and the last 35 per cent is not productive. In 1953 the production of wood was  $1.05 \times 10^9$  cu m, corresponding to  $0.42 \times 10^9$  tons. With an efficiency of combustion of 4000 kcal per kg, the fuel value is only 0.007 Q. However, most of the wood production will be used as building material instead of fuel. Even if the present wood area is doubled in the future and this increase is destined entirely for fuel purposes, only 0.01 Q per year will be gained, i.e., 10 per cent of the present annual use of energy.

The production of carbohydrate will likely be reserved for food supply in the first place. It is possible to convert carbohydrates by anaerobic fermentation into alcohol, but presumably photosynthesis will not produce enough material to fill our food requirements, let alone our fuel needs.

#### FOOD SUPPLY AND WORLD POPULATION

It is interesting to estimate how much the world population may grow in comparison with the food the available land can produce. From recently published information of the F.A.O., we learn that 10 per cent of the land area on earth, i.e.,  $13.3 \times 10^6$  sq km, is used as arable land. Moreover, some  $23.6 \times 10^6$  sq km is exploited as grass land. This makes a total of  $37 \times 10^6$  sq km, or, rounded off,  $40 \times 10^6$  sq km.

Whether this agricultural area will be increased in the future is an open question. According to the F.A.O., another 42 per cent could be suitable for agriculture. We can consider this figure as an extreme maximum. A more realistic value is the enlargement by  $15 \times 10^6$  sq km (as given by Osborn), sufficient for the food supply of  $10^9$  men. On this basis we could expect that about  $55 \times 10^6$  sq km can feed a population of  $3.5 \times 10^9$  men (the expected population of the earth in the year 2000). Calculating with an average food norm of 2500 kcal per man per day, this population will need 0.0125 Q per year as food, i.e., photosynthetic energy.

As well as food, mankind also needs clothing, for which fibres like cotton, wool, silk, jute, etc., have to be grown. The fuel value of the quantity of fibres grown in 1954 amounts to 0.007 Q.

Finally, livestock and fish are needed, not only for protein production, but also for numerous industrial raw materials like train-oil, skins, wool, hair, etc. In 1953/54 the world livestock, so far as is registered, was composed of 815 million cows, 855 million sheep, and 350 million pigs. With a total weight of  $250 \times 10^6$  ton and a respiration of 50 kcal per kg weight per day,

we arrive at a quantity of energy equal to 0.02 Q that must be brought in as a minimum amount of photosynthetic energy. The world fish consumption is  $25 \times 10^6$  ton per year, corresponding to  $10^{-4}$  Q. This quantity is negligible.

Altogether, the population of  $3.5 \times 10^9$  men will need at least 0.05 Q of photosynthetic material for the first necessities of life. By way of precaution we shall make this quantity 0.1 Q. As the radiant energy of the sun falling on  $55 \times 10^6$  sq km amounts to 250 Q, of which 50 per cent or 125 Q is useful for photosynthesis, we see that the efficiency of the conversion is only 0.08 per cent. This very low output can hardly be increased, as the living cell is playing the biggest part in this synthesis.

#### WHAT IS THE MEANING OF TECHNOLOGY IN THIS LIMITED SOCIETY?

It is interesting to consider the moment when all the known sources of energy will be exhausted and mankind will be dependent upon the sun alone.

First of all, mankind will have to choose the warm parts of the earth for his home. This will be the territory approximately between the parallels of  $30^\circ\text{N}$  and  $30^\circ\text{S}$ , comprising half the earth's surface. In this zone 20 per cent is occupied by land, i.e.,  $\frac{1}{2} \times \frac{1}{5} \times 500 \times 10^6$ , or  $50 \times 10^6$  sq km, or only 10 per cent of the earth's surface.

The sun's energy on this area is  $0.1 \times 2300$ , or 230 Q per year. To get an idea of the extent and the technical difficulties involved in solar energy, imagine that only 0.1 per cent of this energy is used; that means a production of 0.23 Q per year. This is about 2.5 times the present consumption. The difficulty lies in the fact that not only does the energy reach us at a very low temperature level, but also the operations have to work intermittently because the sun does not shine by night.

The area between the  $30^\circ$  parallels also has the advantage that the days and nights are practically equal throughout the year. For this reason, it is conceivable that in this zone some six large stations will be built at distances of 60 degrees of longitude, e.g., in the Sahara, Persia, Australia, an isle in the neighbourhood of the date-line, Mexico, and Venezuela. Every station would produce an average of 0.04 Q per year, i.e.,  $10^{16}$  kcal per year. The average energy falling per sq m per year on the earth amounts to 1350 kwh, or  $1.16 \times 10^6$  kcal. The surface used per station would be about  $10^{10}$  sq m. This is a square with a side of one geographical degree ( $100 \times 100$  km). The efficiency of such an installation would not be over 10 per cent. The quantity of energy per station would only be 0.004 Q, making a total of 0.024 Q. Apart from the very great difficulties of mirror construction (these must be able to follow

the sun) and transport of the energy, it is already clear that by this method only 24 per cent of today's requirement of 0.1 Q could be produced. If we used a reflector of parabolic mirrors of 1000 sq m, then each station must be equipped with 10 millions of these reflectors. It appears that mankind is returning slowly but surely to a period somewhat comparable with the iron age of the old civilization, when only individuals will use private, energy-producing installations with a power of, say  $10^7$  kcal per year. Such an installation requires a mirror surface of about 10 sq m. The energy production agrees with the average consumption per head of the population at present, i.e.,  $10^7$  kcal per year. This amount would be more than sufficient; probably 20 per cent of it would be adequate for the relatively primitive life in warm countries.

It has been mentioned already that the food supply can be sufficient for a population of 3.5 milliard men living at a food standard of 2500 kcal per head per day. For this supply, an agricultural area of  $55 \times 10^6$  sq km is needed. This is 10 per cent more than the land area between  $30^\circ\text{N}$  and  $30^\circ\text{S}$ . This land is not entirely suitable for agriculture, as it includes the following areas:

- 30 per cent desert— $15 \times 10^6$  sq km destined for solar energy regenerators,
- 20 per cent livable area— $10 \times 10^6$  sq km,
- 50 per cent agricultural area— $25 \times 10^6$  sq km.

In these tropical regions we should not expect too great results from agriculture. Moreover, the area is too small. Mankind will be obliged to maintain as much as possible the present agricultural areas that are situated for the most part between the  $30^\circ$  and  $60^\circ\text{N}$  parallels. This means that these areas can serve as arable land only during the summer. In winter these districts will be practically uninhabitable, so that people will be obliged to return to the  $30^\circ\text{N}$ – $30^\circ\text{S}$  zone. With a population of  $4 \times 10^9$ , this means a population density of 400 men per sq km, i.e., about twice as much as the present density in Japan.

Such a situation makes a high demand on science and technology.

#### **ARE THERE STILL OTHER METHODS FOR OBTAINING ENERGY FOR MANKIND?**

The answer is in the affirmative. The above-mentioned sources are, with a single exception, derived from the power of attraction between the sun and moon and the earth, the kinetic energy of the rotation around its axis, and the radiation of the sun. We can distinguish the following sources:

- (1) motion of the tide,
- (2) undulation,
- (3) wind,

- (4) temperature differences in the sea,
- (5) geothermal energy,
- (6) hydro energy.

#### **(1) Motion of the Tide, Ebb and Flow Power Stations**

At present, this kinetic energy is lost in shallow sea areas where it is transformed into frictional heat of the liquid. The utilization of this kind of energy is very expensive, for in the ocean the amplitude is only 60 cm at high tide and 45 cm at low tide. In shallow bays and fjords the differences in level can diverge greatly, e.g., up to 12 m at spring tide and 6.5 m at neap tide at the mouth of the river Severn in the southwest of England.

In the past there have been plans for tide power stations, but up to now nothing has been realized because of the very low economic return. Perhaps this situation will change in the next hundred years. There are already indications that in Europe these sources will be exploited. In France an installation is under construction at the mouth of the river Rance near St. Malo in Brittany. This installation, consisting of 38 units of 9 mw each, must be ready in 1963 and must deliver a quantity of energy of 340 mw. The investment cost is about \$290 per kw.<sup>3</sup> The floods as well as the ebb current will be utilized by means of basins used as a buffer. In this way, the production is continuous. Outside Europe a 400-mw installation could be built in the northeast corner of the United States near the Cobscook and Passamaquoddy Bay, west of Nova Scotia. The construction of this ebb tide power station was started in 1935, but it has not been finished. Perhaps shortly the building operations will be resumed.

#### **(2) Undulation**

Because the wind blows over the surface of the sea, whirls are formed as a result of the friction between air and water. This causes a change of the air velocity. The kinetic energy of the air is transformed into potential energy of the water; waves are formed in the sea surface. The sea swell is caused by vertical level oscillation and has to be distinguished from the surf, the wave-runners on the beach. This horizontal water movement is less suitable for energy production.

Using the up-and-down movement of big floats, it is theoretically possible to trap this kind of energy. The installations must be built in the open sea and must be heavy and strong enough to resist hurricane forces. In calms there would be no production. This process has not yet been worked out; it will be a very expensive and perhaps hypothetical solution.

#### **(3) Windpower**

This driving force was applied frequently in Holland

in the seventeenth century. During the nineteenth century the construction of the Dutch mills was much improved by the use of iron. In 1920 the mill arms were streamlined, giving an increase in efficiency of 50 per cent. However, the windmill was no match for the diesel and electric pumping engines. Of the 7500 windmills in Holland there remain at present only about 1000-1200. In the United States the iron-constructed *wind-motor* was introduced.

Using developments in aerodynamics, the windmill can be still further improved, so that it may be possible to use it for energy production, especially in flat, windy, and fuel-poor countries. Interesting projects have already been worked out, but not yet realized. We may mention the idea of Honnef<sup>4</sup>—constructing paddle wheels of 160 m diameter on a tower of 250 m high, from which a maximum power of 100 mw could be obtained. For a project, technically the most perfect devised and with an estimated power of 1000 kw, we refer to Palmer and Putnam.<sup>5</sup> Even this beautiful engineer's creation was abandoned and unfortunately has to wait for worse times for mankind.

At present windpower is important only in remote areas, where diesel oil is scarce and expensive. In one area of this type, at the Krim in Russia, even before the war hundreds of installations had been built.

Best known converter of this kind is the wind-motor unit of maximum 110 kw, coupled to a dynamo of 93 kw. It needs an accumulator for periods of calms. It is significant that even at present the problem of generation of electricity by windpower is being studied, as at the British Electrical and Allied Research Association in London. There are now available small units with a power of 5 kw costing from \$400 to \$550 per kw; medium units with a power of 5-80 kw and costing \$280-\$400 per kw; and large units with a power of 100-200 kw and costing \$140-\$280 per kw.

#### (4) Use of Temperature Differences in Seawater

If there is a temperature difference, the heat can be degraded and partly transformed to mechanical power. In the oceans there exists a temperature difference between the surface and the bottom. In tropical areas this difference is greatest: at the surface the temperature is about 29°C and at a depth of 700 m about 5°C. About 25 years ago the great French inventor George Claude spent millions of his own funds to obtain power in this way. The experiment was carried out about 100 km from the coast near Rio de Janeiro, but unfortunately did not succeed.<sup>6</sup>

This investigation has not been abandoned. At present, a serious study is going on in France, financed by the Office de la Recherche Scientifique Colonial, regarding the construction of an electric power station near Abidjan at the Ivory Coast in Africa. At Cuba and

on the Pacific coast of the United States other experiments are going on.

Combining this process with the distillation of fresh water offers many attractions. In the condenser of the turbine, water is distilled, free of salt. It is in these warm territories that fresh water is of the greatest importance. Some experienced engineers consider these attempts unjustified. Against the background of impending exhausted energy sources this statement loses its significance.

#### (5) Geothermal Energy

The temperature of the earth's crust increases by 1°C for every 30-100 m depth. As the rocks have a bad conductivity, it is impossible to evaluate the heat transported through the stones. Only where water penetrates deeply and returns elsewhere as steam through sand or porous rocks can earth heat possibly be utilized. Up to a few years ago Italy was the only country where geothermal energy was utilized. It was the Prince of Conti who developed this source near Lardarello. Steam is superheated, mixed with gases, and polluted with borax. This steam cannot be used in turbines because of corrosion difficulties, but by means of heat exchangers the heat is transferred to a circulating system of fresh water that can be transformed into steam suitable for turbines. The cycle is closed by condensing the steam output of the turbines and returning the water to the heat exchangers. Boric acid, hydrogen sulfide, and sulfur are the by-products of this process.

Italy has had an experience of over fifty years in this field. About 160 steam sources near Lardarello in Toscane produce up to a power of 25 mw. However, technical developments are not limited to Italy. In Japan there is a plant of 30 kw; extension up to 3000 kw is underway. Belgium has a unit of 275 kw in the Katanga Mines. New Zealand is building an installation of 37.5 mw and Mexico one of 3.5 mw in the state of Hidalgo.

#### (6) Waterpower

Waterpower is another part of the sun's energy. The investment costs of such a power station are very high. On the other hand, there are considerable advantages: the operation and maintenance costs are relatively low, while 80 per cent of the available energy can be transformed to electricity as opposed to only 20 per cent using coal. For fuel-poor countries like Scandinavia, Switzerland, and France, hydro energy is a vital necessity. At present, 2 per cent of the annual consumption of 0.1 Q per year is supplied with waterpower. In future, these 0.002 Q may be increased to 0.018 Q. At present, 11.5 per cent of the world capacity is used; this estimate amounts to about  $750 \times 10^6$  hp.

It is interesting to compare the investment costs of

the different energy production methods. This comparison is only valid for the present time.

Conventional energy.....	\$125-150/kw
Geothermic energy.....	\$170-230/kw
Waterpower energy.....	\$250-350/kw
Atomic (splitting) energy.....	\$350-600/kw

## CONCLUSION

In the preceding pages we have discussed the ever increasing material needs that make it necessary to use increasing quantities of raw materials for energy production. We have shown that it is probable that the reserves of fossil fuels will be used up within a couple of ages. Some intelligent men expect to be able to use atomic fission to replace them. However, we know that within 25 years not more than about 10 per cent of our energy needs can be covered by this form of energy.

Homo sapiens will undoubtedly quicken the pace of development; homo faber will improve and enlarge the digging of raw materials. All these remedies, however, only provide a respite. Even if we suppose that atomic fusion could be achieved on earth—an idea that at present is still far from reality—even then, the raw materials will be exhausted after five or six centuries. Mankind will have many fewer material needs long before this moment arrives.

This paper gives a future forecast, both of energy provision and of the supply of industrial raw materials used as energy. Man should realize that if we use raw materials, especially in metallurgical plants, we can hardly avoid the element carbon. Another important problem is that the gasoline motor cannot be replaced by nuclear generators in all cases. Perhaps this situation can be alleviated by using alcohol from the fermentation of carbohydrates. Alcohol and even synthetic rubber production was practised in Russia before the war, starting from starch, a product of the photosynthesis. However, the difficulty remains that there will be no material for the construction of the motor. The consequences of this situation are far from exciting. Imagine the earth without energy sources and without raw materials. Imagine that mankind has to retire to the zone around the equator between 30°N and 30°S. In this situation mankind will be dependent on the heat of the sun both for inspired as well as uninspired energy.

We have seen that trapping the energy of the sun is not a simple task. A production of only a quarter of the present annual energy needs requires the construction of installations bordering on a technical impossibility. Besides this problem, there is the much bigger problem of obtaining our food supply, limited by the efficiency of photosynthesis. Using the available land surface between the parallels mentioned, the density of the population could be a maximum of  $4 \times 10^9$  men, i.e., 400 men per sq km.

It is self-evident that intelligent men should obtain energy by methods other than the conventional ones. Mankind is living in a sea of energy—solar radiation, tidal energy, kinetic energy of the rotation of the earth. However, it must be transformed for conventional applications. Most suitable for this purpose will be the radiant energy of the sun. The situation regarding the application of natural energy today compared with that predicted for 25 years hence may be considered as follows:

Energy	1958	1983
Wood (product of photosynthesis).....	0.0010	0.0015
Utilizing waste material (fermentation).....	0.0001	0.0005
Waterpower.....	0.0008	0.0015
Windpower.....	0.0001	0.0002
Temperature difference in the sea.....	—	0.0001
Tide movement.....	—	0.0001
Geothermal energy.....	—	0.0005
Undulation.....	—	0.0001
Total (Q).....	0.0020	0.0045

From this table we see that of the world consumption of 0.1 Q per year in 1958, the energy from natural sources is only 2 per cent, of which about one-half is delivered by water power. At a rough estimate, the absolute quantity can be increased by a factor of 2.25. However, in 1983 the world consumption will be 0.26-0.27 Q (with a 4 per cent increase per year). This means that in 25 years still no more than 2 per cent can be supplied by nature.

From this point of view, it is somewhat strange that mankind is directing its efforts to the development of modern production processes which may be of little value, whereas it is possible to obtain "new" power from "old" sources. In the meantime, the problem of the energy supply for cultural needs is not the most important; to maintain and to enlarge the present standard of life in many areas is a problem of the first order. This last problem, however, is dependent upon photosynthesis and that, in turn, is controlled fundamentally by the assimilating cell. Therefore, as long as mankind does not understand the working of nature, he will not succeed in controlling this process nor other, related processes.

*Natura parendo vincitur*

## REFERENCES

1. P. Putnam, *Energy in the future*. N. Y., 1953.
2. *Petroleum Refiner* 1959 (1): 192.
3. U. N. Dept. of Economic and Social Affairs, *New sources of energy and economic development*. N. Y., 1957.
4. H. Honnep, *Windkraftwerke*, 1932.
5. Palmer and Putnam, *Power from the wind*. 1948.
6. George Claude, *Mem. Soc. Ing. Civil* 1943: 1482. Also, *L'Expedition de la Tunisie*. 1935. p. 325.
7. H. Borchert, *Geochimica et Cosmochimica Acta* 2(1): 62, 1951.

# A Proposed Standard Test Code for the Determination of the Efficiency of Solar Water Heaters of the Flat Collector Type

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The properties which must be considered in obtaining an objective estimate of the quality of a flat-plate-type solar water heater are listed. Methods are given for calculating the aerial, orientation, and thermal efficiency of the heater and the heat storage coefficient. A test procedure is outlined for making an objective standard determination of the efficiency of the heater, and a standardized sheet form is given on which the results can be tabulated.

## INTRODUCTION

In the last few years a number of solar heaters have been brought to the market, and each inventor and producer has claimed a higher efficiency for his product than that achieved by any other. It is, in fact, difficult to check and compare the efficiency of solar heaters without testing them by a method which can be applied to the majority of them in a manner enabling the results of the tests to be compared easily and clearly. A great number of parameters and environmental conditions which cannot be controlled and maintained in a steady state during the test are involved in the procedure, such as solar radiation, cloudiness, wind velocity, humidity, etc. Some limitations must be set to enable a test to be comparable and reproducible under various conditions.

Clearly defined criteria must be obtained by measurement and calculation to avoid misunderstandings which can arise in cases where some producers are ready to sacrifice certain properties of the heater for others, such as high temperature for large quantity of hot water, or vice versa.

The intention of this paper is to establish a procedure and some standards which will be acceptable to all interested parties, in terms comprehensible to scientists, engineers, salesmen, and customers.

## PROPERTIES OF A SOLAR WATER HEATER

To obtain an objective estimate of the quality of the tested heater, the following properties should be examined:

- (1) Total net exposed area, taking into account only the area of the collector which is active in absorbing the incoming radiation.
- (2) Area required for the installation and maintenance, total and per U.N.E.A.\*
- (3) Weight of the installation per U.N.E.A. characterising the specific weight of the installation in relation to the useful exposed area.
- (4) Volumetric data, giving accurate volumetric capacities of:
  - (a) absorber-collector,
  - (b) storage tanks,
  - (c) piping and other containers.
- (5) Maximum pressure which can safely be applied to the various parts of the heater when the unit is to be used under direct pressure.
- (6) Weather resistance.
- (7) Corrosion resistance of the parts in contact with the heated water and the parts in contact with the air humidity.
- (8) Quantity of insulating material used per U.N.E.A. and properties of the insulating material used:
  - (a) thermal conductivity coefficient,
  - (b) specific weight,
  - (c) heat capacity,
  - (d) hygroscopic properties.
- (9) Arrangements for water treatment, including possibilities for descaling, cleaning, and draining; also hygienic properties with regard to elimination of all possible contamination (acceptable to local medical authorities).

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\* U.N.E.A.—Unit Net Exposed Area, i.e., a unit of area taking active part in collecting energy through radiation from the sun. This unit will be used as a reference value for size and performance of the installation.

(10) Materials used, in detail, for every part of the water heater-collector, storage tank and pipes—and their physical and chemical properties.

## THE EFFICIENCY OF THE HEATER

### (1) Aerial Efficiency

The term "aerial efficiency" involves the relation of the area under and around the installation used for regular operation and maintenance to the net exposed area taking active part in absorbing the incoming energy. The aerial efficiency is calculated by dividing the N.E.A. by the total area.

$$\eta_a = A_{net}/A_{total} \quad [1]$$

### (2) Orientation Efficiency

To define the relationship between the N.E.A. and the area of the projection of the N.E.A. perpendicular to the incoming sun's rays, the mean daily value of the angle between the incoming rays and a perpendicular to the N.E.A. must be calculated as follows:

$$\psi_m = \frac{1}{\tau} \int_0^{\text{day}} \psi dt$$

and the orientation efficiency will be:

$$\eta_{or} = \cos \psi_m$$

For example, an absorber mounted on a rotating device following a plane perpendicular to the direction of the incoming sun's rays during the day and year will have  $\psi = 0$  for any instant and consequently  $\psi_m$  will be 0 too. From this it follows that for such a device the orientation efficiency will be 100 per cent.

### (3) Thermal Efficiency

To calculate the thermal efficiency of the heater, the incoming radiation, in this case the energy input, should be measured by an Eppley global pyrheliometer, or similar instrument measuring the total radiation, placed near the absorber, its receiving area being positioned towards the sun identically with that of the collector.

The useful heat should be expressed in quantities of water and temperature rise. These data should be measured by the usual methods approved in other standard tests.

The thermal efficiency is defined as the ratio of the heat input (by solar radiation) to the heat transferred to the water

$$\eta_{th} = \frac{G \Delta T}{i_m \tau A_{NEA}} \quad [2]$$

where  $G$  is the weight of the heated water,  $\Delta T$  temperature increase in degrees C of the heated water during

time period  $\tau$ . The temperature of the water in the storage tank is a calculated average for at least three different characteristic points inside the storage tank.  $i_m$  is the mean radiation intensity, obtained as follows:

$$i_m = \frac{1}{\tau} \int_0^{\tau} i dt \quad [3]$$

where  $i$  is the reading of the pyrheliometer and  $t$  the time.

Besides the thermal efficiency defined in Formula (2), which may be termed the "practical thermal efficiency," a "physical thermal efficiency of the collector" may be considered. The latter is determined as follows: it is a fraction with a numerator giving the actual amount of heat absorbed by the water during the flow through the collector and a denominator with  $\Delta i_m$  instead of  $i_m$  as in Formula (2). The value  $\Delta i_m$  is the real amount of solar radiation energy used for the heating of the flowing water:

$$\Delta i_m = i_m - i_{loss}$$

$i_{loss}$  are the losses from the incoming radiation, composed of the reflection and absorption by the glass sheets, reflection and dark radiation from the upper surface of the collector, and the heat losses from the glass sheets by wind and dark radiation. This form of efficiency is of a physical character and will not be treated here; for details see References 1 and 2.

### (4) Heat Storage Coefficient

One of the most important properties of a solar water heater is the ability to store the heat absorbed during the hours when the radiation is weak or zero. This property depends mostly on the insulation of the storage tank, the quantity of water contained in the absorber, and the circulation system. As an over-all guide for the above properties, the heat storage coefficient is defined as the decrease in temperature of the stored hot water per hour divided by the temperature difference between the mean water temperature and the surrounding temperature, for a period when the radiation  $i$  equals zero.

$$\rho_{stor.} = \frac{T_{w1} - T_{w2}}{\frac{T_{w1} + T_{w2}}{2} - T_a}$$

The above results should be represented in the form of diagrams:  $\eta_{th}$  should be plotted against  $T_m$  (mean water temperature for period  $\tau$ ) and  $\rho_{stor}$  should be plotted against  $T_m$ .

## TEST PROCEDURE

### (1) Weather Conditions

To enable results to be compared, the test should be carried out under conditions which prevail during a

reasonable number of days in the year, bearing in mind the following limitations:

- (a) The sunshine duration should not be less than 75 per cent of the theoretical possible on the test day. A lower percentage would distort the results and a good reproducibility could not be achieved.
- (b) Wind velocity should not exceed 20 km per hr for 50 per cent of the day, thus eliminating excessive convective heat losses from the system due to the wind.
- (c) Days with excessive dust, mist, or other particles in the air should be avoided. A day with sky with more than 20 per cent cloud cover should not be regarded as suitable, nor should a day on which the readings of a normal incidence pyrheliometer are lower than 80 per cent of the reading obtained on clear days or of values given in tables for similar geographical position and season.

## (2) Water Consumption

Various methods of water extraction should be tested:

- (a) A test should be carried out in which water is not extracted from the system for at least three consecutive days. This test will supply data for calculations of  $\eta_{th}$  and  $\rho_{el,or}$ .
- (b) A series of tests should be carried out in which water is extracted in accordance with the instructions of the party requesting the test; i.e., hot water should be taken from the system in various quantities and during various periods according to the size and purpose of the heater. It is obvious that a heater for hot water supply for a workers' bath will have completely different duties from a household or hospital heater.
- (c) To prove the supply capacity of the heater an almost constant temperature test should be carried out; i.e., during a day the maximum quantity of water at a constant temperature should be taken from the heater. The procedure of this test should be as follows:

The standard supply temperature will be 60°C (or if higher, this must be specified). The temperature on the drain-off point must reach at least 60°C; then water will be taken from the heater till the temperature of the outgoing water drops 5°C, i.e., to 55°C. The quantity of extracted water must be measured and recorded.

This procedure should be repeated and the result given as total of water extracted during the day. The quantities and times of each extraction should also be given.

## (3) Measurements

The following measurements, in addition to those mentioned above, should be taken:

- (a) pyrheliometer reading,
- (b) surrounding temperature,
- (c) temperature of at least three characteristic points in the water system representing not less than 90 per cent of the water quantity, (if a storage tank is included in the system the temperature of the water at the bottom, middle and top should be measured)
- (d) wind velocity,
- (e) total sun and sky radiation on a surface parallel to that of the collector,
- (f) sunshine duration.

All readings should be taken at equal intervals of no more than one hour. It is recommended wherever possible that all measurements be recorded by automatic recording instruments.

Calibration of instruments should be carried out before the test according to standard procedures for calibrations of measuring instruments.

## RESULTS

The results should be presented in a standardized sheet form containing all points discussed in this paper. The units used should be clearly noted.

## TEST SHEET

Test no. .... Date: ....  
Requested by: ....  
Carried out by: ....  
Responsible: ....

General description of the system:

- (1) Weight: total ..... kg; per U.N.E.A. .... kg/m<sup>2</sup>
- (2) Area required: total ..... m<sup>2</sup> per U.N.E.A. .... m<sup>2</sup>/m<sup>2</sup>
- (3) Net exposed area ..... m<sup>2</sup>
- (4) Capacity: absorber ..... m<sup>3</sup>  
storage tank ..... m<sup>3</sup>  
piping ..... m<sup>3</sup>
- (5) Maximum pressure ..... at m<sup>3</sup>
- (6) Weather resistance: good, fair, bad
- (7) Insulating material:
  - (a) Quantity ..... m<sup>3</sup> (or kg)
  - (b) Thermal conductivity ( $\kappa$ ) ..... kcal/m/°C/hr

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(e) Specific gravity ..... kg/m<sup>3</sup>  
 (d) Hygroscopic properties: good, fair, bad  
 (e) Heat capacity (C) ..... kcal/kg/°C

(8) Arrangements exist for:  
 (a) water treatment .....  
 (b) descaling .....  
 (c) cleaning and draining .....

(9) Hygienic properties: good, fair, bad

(10) Materials used

Material	Quantity	General Dimensions

(11) Thermal efficiency

$T_m$			
$\eta_{th}$			

(12) Storage coefficient

$T_m$			
$\rho_{stor.}$			

(13) Aerial efficiency:  $\eta_a$  .....

(14) Orientation efficiency:  $\eta_{or}$  .....

#### REFERENCES

1. N. Robinson, "Solar machines." (In: *Proceedings of the World Symposium on Applied Solar Energy, 1955.*)
2. H. Tabor, *Bull. Res. Council Israel* 5A: 129, 1955. Also, *J. Sci. Instr.* 33: 356, 1956.

# Design Consideration for a High Reliability Photovoltaic Solar Energy Converter

By J. F. Elliott

Advanced Semiconductor Laboratory, General Electric Company, Syracuse, New York

Solar radiation data have been examined to determine the storage requirements for a photovoltaic solar energy conversion system having a high reliability. It has been found that a low failure rate can be obtained with one and one-half days' storage if the demand power rate is set at about one-half the winter's average daily production rate.

High reliability is the primary consideration of a system which provides electrical power for home consumption. For the particular case where the power is produced by the photovoltaic conversion of solar radiation, this reliability can be obtained by various combinations of daily production rates and amounts of electrical storage for any given demand power specification. The particular combination of production rate and storage capacity is determined by economic considerations. If the solar energy converter is a five per cent efficient device made from a thin film of silicon, a cost analysis has shown that the price of a unit area of such a converter will be about the same as the cost of a battery to store the one day's electrical production of the area.\*

Solar radiation data for various locations in the United States for the winters of 1954-55 to 1957-58<sup>1</sup> have been examined in order to determine how a system must be designed for high reliability. This has been done by investigating the power available each day for various combinations of the ratio of the demand power rate to the average power produced rate ( $P_d/P_p$ ), and amounts of available storage.

It was soon evident that if the demand power rate was set at the average production rate (i.e.,  $P_d/P_p \approx 1$ ) that prohibitive amounts of storage would be required. For example, the amount of power available per day for such a system with a four-day storage in Los Angeles during the winter of 1955-56† is shown in Fig. 1b. The

\* Assuming that the average daily solar energy is about 300 ly per day.

† According to the Weather Bureau, the winter of 1955-56 was the most deficient in sunshine of any winter on record for Los Angeles.

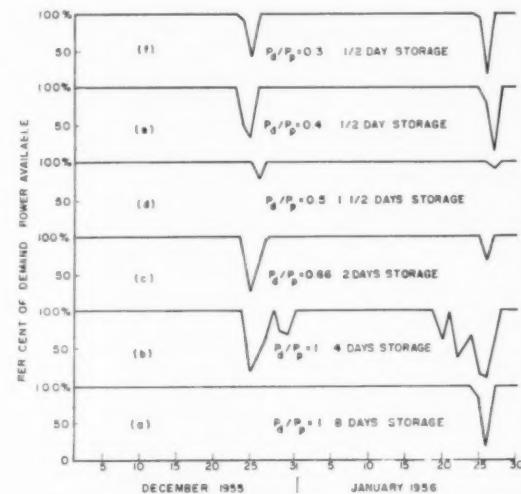


FIG. 1.—Per cent of demand power available with various storage requirements, for winter of 1955-56 in Los Angeles.

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TABLE I

Location	Year	$P_d/P_p = 1$ Storage for 100 per cent reliability (No. of days)	$P_d/P_p = \frac{1}{2}, 1\frac{1}{2}$ days storage		
			Less than full power (No. of days)	Less than $\frac{1}{2}$ power (No. of days)	Less than $\frac{1}{4}$ power (No. of days)
Brownsville, Texas	57-58	8.5	2	0	0
Lake Charles, La.	56-57	5.4	2	0	0
Oak Ridge, Tenn.	56-57	8.1	2	0	0
Columbia, Mo.	56-57	6.5	0	0	0
Blue Hill, Mass.	55-56	8.3	6	5	1
Washington, D. C.	56-57	5.5	0	0	0
Seattle, Washington	54-55	7.4	0	0	0
Los Angeles, Calif.	55-56	10.0	0	0	0
Albuquerque, N. M.	56-57	4.6	0	0	0
Indianapolis, Ind.	56-57	9.2	3	2	1

addition of extra storage does little towards improving the reliability (Fig. 1a). In fact, a ten-day storage would have been required to insure that full power was available every day. Similar results were found for other locations (Table I).

By reducing the ratio of ( $P_d/P_p$ ) the storage requirements were considerably reduced, as is shown in Fig.

1e-f, for the same winter in Los Angeles. A system having a  $P_d/P_p \approx 0.5$  with a one and one-half days' storage is seen to have a high reliability (Fig. 1d).

The solar radiation data from other locations have been examined in a similar manner as that from Los Angeles. It has been found that low failure rates can be obtained in the same manner. Some of the reliability data for the winters having long periods of less than

average solar radiation for various locations are summarized in Table I. A particular effort has been made to include in the table those winters and locations which put the most severe strain on the high reliability requirement.

#### REFERENCE

1. *Climatological Data, National Summary, U.S. Dept. of Commerce, Weather Bureau.*

## The Minimum Average Daily Solar Radiation in the United States During December for a Tilted Flat-Plate Collector

By J. F. Elliott

Advanced Semiconductor Laboratory, General Electric Company, Syracuse, New York

**The minimum average daily solar radiation in the United States during the month of December for a tilted flat-plate collector is presented by means of lines of constant radiation density on a map. Such data are useful in determining the economic feasibility of photovoltaic power generating systems where a given daily demand power is required.**

In considering the economic feasibility of providing individual homes with electrical power by means of the photovoltaic conversion of solar energy, it is necessary to know the monetary value of the power converted. This value can be computed for any particular geographic location and converter efficiency, provided suitable solar radiation data are available. For two reasons, previous studies<sup>1, 2, 3</sup> on the geographical distribution of solar radiation are not applicable to this particular problem. (a) Since a converter for this application must approach 100 per cent reliability, it is necessary to obtain a daily rate of radiation which is indicative of the worst possible condition. Average daily solar radiation rates by years or by months are too high and are not satisfactory. (b) For various reasons, it appears desirable to use a flat-plate collector which is permanently tilted toward the south at an angle with the horizontal equal to the latitude of the geographic location. Thus, the horizontal flat-plate data collected by the U. S. Weather Bureau are not directly applicable.

In this initial feasibility study, four years of solar radiation data (1954-57) have been examined for some fifty-five geographical locations.<sup>4</sup> We have defined as the value of daily radiation which is indicative of the worst possible conditions as being the daily average during the month of December. The averaging was performed on the particular December during the above period which had the lowest total radiation for the month.

Having decided over what period the radiation is to be averaged, it is now necessary to correct the horizontal flat-plate collector data to a tilted flat-plate collector. Multiplying each daily rate by the correction factor corresponding to the particular latitude is not satisfactory, since it is only the direct radiation per unit area that is affected by the tilting and not the diffuse radiation. Our method of correcting the Weather Bureau data has been to multiply the daily radiation rates which are above the December average daily radiation rates<sup>1</sup> by the latitude correction and leave unchanged those rates which are below the average.\* We have thus assumed that on those days on which the radiation is above the average, it is entirely direct radiation and on those days for which the rate is below the average it is entirely diffuse radiation. This method of correction, of course, tends to give too high a correc-

\* For another suggestion of how to make this correction see: Fritz, S., "Transmission of solar energy through the earth's clear and cloudy atmosphere" *Transactions of Conference on the Use of Solar Energy, Tucson, Ariz., 1955*, Vol. 1.

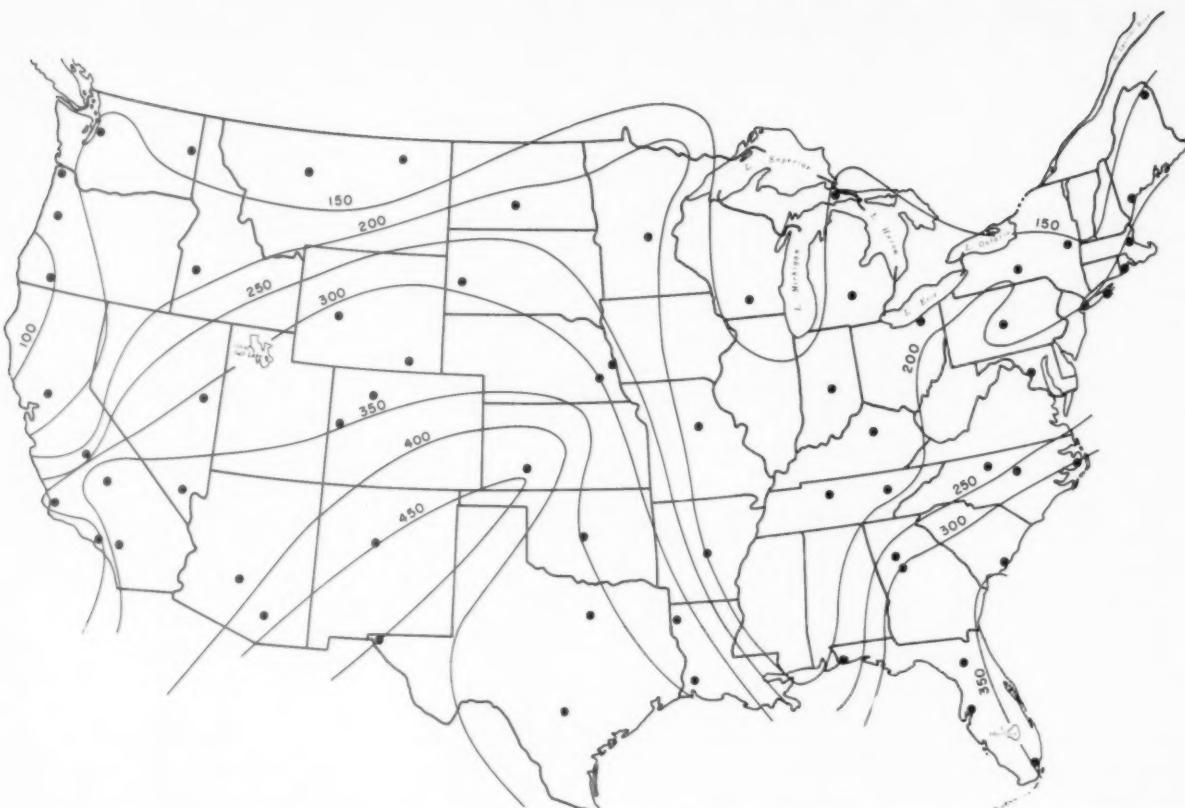


FIG. 1—The minimum average daily solar radiation in the United States during December for a tilted flat plate collector. The units are langleys. Dots are U.S. Weather Bureau stations recording solar radiation.

tion for predominantly cloudy areas and too small a correction for sunny areas.

The method of correcting the horizontal data has been checked by using the total radiation and diffuse radiation data from Blue Hill, Mass.<sup>4</sup> The comparison of the actual corrected December average daily radiation rate with the average rate computed by our method is shown in Table I.

TABLE I

A COMPARISON OF THE ACTUAL DECEMBER AVERAGE RADIATION RATE WITH THE AVERAGE RATE COMPUTED BY OUR METHOD, USING THE SOLAR RADIATION DATA FROM BLUE HILL, MASS.

Year	Actual rate (ly/day)	Our method (ly/day)	Error (%)
1954	185	198	7
1955	265	312	17
1956	187	218	17
1957	226	243	7

As expected, our method gives rates which are high but which are in error by less than 20 per cent.

A summary of the data examined and corrected is

presented in Fig. 1 by means of lines of constant radiation density on a map.

If and when it appears that the use of solar photovoltaic power sources are economically competitive with other power sources, it will be necessary to further refine the above data. In particular, the period over which the averaging is carried out must be considerably reduced. Furthermore, since one is interested in extreme values, extreme value statistics should be used.<sup>5</sup> The use of this type of statistics would permit the determination of the amount of storage required for a given demand power requirement and failure rate.

## REFERENCES

1. I. F. Hand, "Distribution of solar energy over the United States," *Heat. & Vent.*, July 1953.
2. S. Fritz; T. H. MacDonald, "Average solar radiation in the United States," *Heat. & Vent.*, July 1949.
3. S. Fritz, "Solar radiation on cloudless days," *Heat. & Vent.*, Jan. 1949.
4. *Climatological Data, National Summary*. U.S. Dept. of Commerce, Weather Bureau.
5. E. J. Gumbel, "Statistical theory of extreme values and some practical applications," *Nat. Bur. Stand. Appl. Math. Ser. No. 33*, Feb. 12, 1954.

# Solution of Equations of a Thermal Network on a Digital Computer

By A. J. Ness

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A model of a solid body emitting heat by radiation as well as by conduction and convection may be represented by a network of thermal resistances. These thermal circuits can then be analyzed, similar to electrical networks, for the temperatures at the various nodes. There will be produced in this analysis a set of equations describing the temperature balance around each closed loop. These equations are not necessarily linear, since the radiating surfaces will be represented by temperatures raised to the fourth power in accordance with the Stefan-Boltzmann Law. A direct method of solving the set is not known so that one is forced to use numerical techniques and high speed digital computers to achieve the results expeditiously.

## SOLVING THE NETWORK EQUATIONS

Of the various numerical methods for finding the roots of the set of nonlinear algebraic equations, it is desirable that the one selected have the properties required for computer solution. That is, any method which fails to converge on the roots when the initial guess of temperatures is far from the final values should be avoided. The Newton-Raphson method<sup>1</sup> does avoid these limitations. It consists of solving an auxiliary set of linear equations for correction factors by which the temperatures are modified. By repeated evaluations using the improved temperature values, the correction factors will diminish to less than a preset value. Thus, any prescribed level of precision may be achieved.

Let the original set of equations be

$$\begin{aligned}f_1 &= (a_{11}t_1 + a'_{11}t_1^4) + (a_{12}t_2 + a'_{12}t_2^4) + \dots \\&\quad + (a_{1n}t_n + a'_{1n}t_n^4) - b_1 = 0 \\f_i &= (a_{ii}t_i + a'_{ii}t_i^4) + \dots \\&\quad + (a_{ij}t_j + a'_{ij}t_j^4) + \dots - b_i = 0 \quad [1] \\f_n &= (a_{nn}t_n + a'_{nn}t_n^4) + \dots \\&\quad + (a_{n1}t_1 + a'_{n1}t_1^4) - b_n = 0\end{aligned}$$

The  $j$ th temperature is represented as  $t_j$ , and its coefficient is  $a_{ij}$ ; the coefficient of  $t_j^4$  is  $a'_{ij}$ .

Now if  $t_{j0}$  is an approximate value of the  $j$ th temperature and  $h_j$  a correction factor, then

$$t_j = h_j + t_{j0}$$

In accordance with the Newton-Raphson method, a set of linear equations must be solved for each  $h_j$ :

$$\begin{aligned}f_{11}h_1 + f_{12}h_2 + \dots + f_{1n}h_n + f_1 &= 0 \\f_{n1}h_1 + f_{n2}h_2 + \dots + f_{nn}h_n + f_n &= 0 \quad [2]\end{aligned}$$

in which

$$f_{ij} = \frac{\partial f_i}{\partial t_j} = a_{ij} + 4a'_{ij}t_j^3$$

Any standard method of solving the set of linear equations will suffice.

Finally the improved temperatures are evaluated, and the process is repeated until each correction factor is below the minimum limit.

## APPLICATION OF METHOD

The number of temperatures which may be computed depends on the size of the computer memory. A 2000-word memory allowed a maximum of sixteen equations to be evaluated. In this case, a considerable portion of the memory was occupied by the program of the Crout Method for solving the linear equations. If floating decimal point accessories were attached, it is estimated that at least twenty equations could be solved.

The speed of solution varies with the number of equations, the closeness of initial temperature guesses to the final results, and the limit imposed upon the size of the correction factors. In one case, a set of fifteen equations was solved in fifty minutes on an IBM-650 computer, the limit on the correction factor being set at one-half percent of the estimated minimum temperature. In this case it turned out that half the initial guesses differed from the final results by at least 100 percent.

## REFERENCE

1. J. B. Scarborough, *Numerical mathematical analysis*, 2nd ed. 1950. p. 203.

# Addendum To: "Solar Collector Surfaces With Wave Length Selective Radiation Characteristics"\*

By T. F. Irvine, Jr., J. P. Hartnett, and E. R. G. Eckert

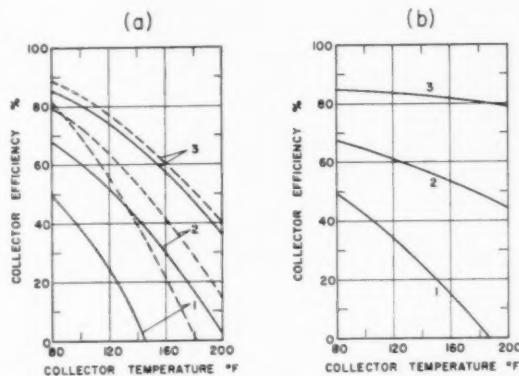
Heat Transfer Laboratory, University of Minnesota, Minneapolis, Minnesota

In a recent paper entitled "Solar Collector Surfaces with Wave Length Selective Radiation Characteristics" we presented measurements of the solar absorptivity and infrared emissivity for a number of porous surfaces. The observed characteristics of large absorptivities and low emissivities suggested their use as collector surfaces for solar energy and a comparison was shown between these porous surfaces and others such as lamp-black and the special surfaces developed by Tabor.<sup>1</sup> Under the conditions chosen for the comparison, the porous and Tabor surfaces were superior to the lamp-black surface.

In a letter to this laboratory, Professor H. C. Hottel of the Massachusetts Institute of Technology pointed out that an additional term has to be included in our energy balance when the solar collector surface is located near the surface of our earth. In this case the collector surface also receives radiation from the atmosphere, which has to be added to the right hand side of Equation [7] in the original paper which defines the collector efficiency. The purpose of this note is to present once more the collector efficiency as defined in our original paper and to indicate the effect of this additional term. The inclusion of this term favors a gray surface in comparison with a selective one.

A literature search indicated that the most probable average value for the radiative flux coming from the atmosphere is two-thirds of the radiative flux from a black body at ambient temperature.<sup>2, 3</sup> In the following comparison this radiative flux is set equivalent to the radiation emitted by a black body at a temperature of 468°R.

The solid lines in Fig. 1(a) show the collector efficiency of three surfaces as they were originally presented without inclusion of the atmospheric radiation term. The dashed lines indicate the efficiency when the radiation from the atmosphere is included. It may be observed that the addition of this term raises the collector



Collector Efficiency vs Collector Temperature, (1) lamp-black paint, (2) Tyler 28 X 500, (3) coated surface.  
(a) Solid lines—convection but no atmospheric radiation.  
Dashed lines—convection and atmospheric radiation.  
(b) No convection or atmospheric radiation.

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efficiency of a lamp-black surface relative to the selective surfaces so that, for instance, the porous Tyler surface has a better efficiency than the lamp-black surface only when the collector surface temperature is greater than 90°F.

An application of solar collectors, which is of current interest, occurs in space flight where radiation from the atmosphere as well as convective heat transfer are zero or negligible. A comparison of the various surfaces for these conditions is presented in Fig. 1(b). The superiority of selective surfaces for this application becomes apparent.

The authors would like to express their appreciation to Professor Hottel for his thoughtful letter which initiated the more complete investigation of collector efficiencies presented in this note.

## REFERENCES

1. Tabor, H., "Selective radiation I: wavelength discrimination," *Bull. Res. Conc. Israel* **5A**: 119, April, 1956.
2. O. G. Sutton, *Micrometeorology, A Study of Physical Processes in the Lowest Layers of the Earth's Atmosphere*, McGraw-Hill Book Co., 1953.
3. Fritz Moller, "Long wave radiation," *Compendium of Meteorology*, American Meteorological Society, Boston, Massachusetts, 1951.

\* Irvine, T. F., Jr., Hartnett, J. P., and Eckert, E. R. G., *Solar Energy*, Vol. II, No. 2-3, 1958, pp. 12-16.

## Solar Abstracts

Arnold, William; Sherwood, Helen, "Energy storage in chloroplasts." *J. Phys. Chem.* **63**(1): 2-4, Jan. 1959. Illus.

Dried chloroplast films that have been illuminated exhibit thermoluminescence. The glow curves have been analyzed to give the activation energies associated with this energy storage. The analysis shows that at least five different activation energies are involved: one at 0.93 ev represents a little less than half of the stored energy; another at 0.69 ev is a minor part; between these two there are two or three unsolved levels that represent the major fraction; finally, unilluminated samples always give a small signal corresponding to an activation energy higher than 0.93 ev. (authors' abstract)

\* \* \*

Bowen, E. J.; Sahu, J., "The effect of temperature on fluorescence of solutions." *J. Phys. Chem.* **63**(1): 4-7, Jan. 1959. Illus.

Measurements have been made of the effect of temperature on the fluorescence yields of substituted anthracenes dissolved in several solvents. 9-substituted anthracenes show high yields and steep temperature dependencies, while side-substituted derivatives have low yields and small temperature variations. The results are interpreted in terms of the following concepts. There appear to be two processes of energy degradation of the excited molecules, a substantially temperature independent one which is probably associated with the singlet-triplet conversion, and a temperature-dependent one having a heat of activation of degradation and a dependence on solvent viscosity which may be associated with a direct transition from excited to the ground state. (authors' abstract)

\* \* \*

Buelow, F. H., "Drying grain with solar heated air." *Quart. Bull. Mich. Agric. Exp. Sta.* **41**(2): 421-29, Nov. 1958. Illus.

Discusses the possibility of reducing grain and hay drying costs on farms by using solar energy for heating the air which is used in the drying process. Energy storage would not be needed because when solar energy is not available, unheated air can be used to prevent the spoilage of grain and hay. Various types of air heaters for grain drying systems discussed in this paper were tested experimentally.

\* \* \*

Buelow, F. H.; Boyd, J. S., "Heating air by solar energy." *Agric. Eng.* **38**(1): 28-30, Jan. 1957. Illus.

Describes the construction and operating characteristics of an air-heating solar collector designed by the authors and discusses the possibilities of using it in a solar heating system on farms.

\* \* \*

Coleman, J. W.; Rabinowitch, Eugene, "Evidence of photoreduction of chlorophyll in vivo." *J. Phys. Chem.* **63**(1): 30-34, Jan. 1959. Illus.

Continuation of a study by Coleman involving the measurement of the difference spectrum of illuminated *Chlorella* cells up to 720 illuminations.

\* \* \*

Dubois, Jean T., "The sensitized fluorescence of  $\beta$ -naphthylamine; a study in transfer of electronic energy." *J. Phys. Chem.* **63**(1): 8-11, Jan. 1959. Illus.

The gas sensitized fluorescence of  $\beta$ -naphthylamine was studied at 150° using benzene as photosensitizer. Amine pressures of 0.53 and 1.25 mm were used. A kinetic mechanism for the transfer of electronic energy is proposed. (author's abstract)

\* \* \*

Duffie, John A.; Lof, G. O. G., "Solar energy; economics and engineering research at the University of Wisconsin." *Canadian J. Chem. Engr.* Apr. 1959: 77-84. Illus.

The probable economic feasibility of several solar applications is assessed by using the costs of energy from present sources as a basis for estimating upper limits on the first cost of solar heat exchangers and their associated equipment. Economic considerations have helped shape the development of the Wisconsin solar energy program, which includes studies of solar heat exchangers and their applications to heating, cooling, and power generation. (authors' abstract)

\* \* \*

Duffie, John A.; Lof, G. O. G.; Salam, Ehab, "Developments in solar energy heat exchangers." Paper presented at the Salt Lake City meeting of the American Institute of Chemical Engineers, Sept. 1958. 30 p. Illus.

Results of recent studies on methods for improving solar heat exchanger performance and reducing costs are presented, including the use of semitransparent coatings on absorber surface to reduce long-wave radiation losses while retaining high absorptivity for short-wave solar radiation. Recent improvements in reflector construction, optical loss reduction, and transparent covers for solar heat exchange surfaces are also discussed. (authors' abstract)

\* \* \*

Eggert, J., "The ignition of explosives by radiation." *J. Phys. Chem.* **63**(1): 11-15, Jan. 1959. Illus.

In the experiments of Norrish and Porter the radiation which is emitted as very high energy within milliseconds by suitable electric discharges serves to dissociate gases, such as chlorine, into atoms or radicals. In these cases the absorbed energy is consumed in making possible one or several chemical processes; the system reacts exclusively with the absorbed energy, even if it returns to the original state afterwards. In this case, the absorbed energy is stored as chemical energy; the system operates just as a plant during photosynthesis.

Principally different is the behavior of a mixture of chlorine and hydrogen; for chlorohydrogen can be caused to detonate by sufficiently large quantities of absorbable radiation and is converted to hydrogen chloride even by radiation of lower intensity with a high quantum yield because in this "endothermic system" chain reactions may occur. (author's abstract)

\* \* \*

Garwin, Richard L., "Solar sailing—a practical method of propulsion within the solar system." *Jet Propulsion* **28**(3): 188-90, Mar. 1958. Illus.

Commercially available metallized plastic film can be used as a solar radiation pressure sail for propulsion of space vehicles within the solar system. The method of propulsion is of negligible cost and is perhaps more powerful than many competing schemes.

\* \* \*

Gilmore, E. H.; Lim, E. C., "A method for evaluating rate constants in the Jablonski model of excited species in rigid glasses." *J. Phys. Chem.* **63**(1): 15-16, Jan. 1959. Illus.

A method is presented for calculating kinetic rate constants for processes that occur according to the Jablonski model of electronically excited dye molecules in rigid glasses. Non-radiative transitions from excited to ground states are considered in addition to the radiative transitions usually considered. Since the rate constants are found by use of data on fluorescence,  $\alpha$ -phosphorescence and  $\beta$ -phosphorescence, the method is limited in use to temperatures above about 180° K. (authors' abstract)

\* \* \*

Giutronich, J. E., "Solar furnaces: the 12-ft diameter furnace project—a progress report." Paper presented at the A.N.Z.A.A.S. Congress Solar Energy Symposium, Adelaide, Australia, Aug. 25, 1957.

The Sydney project involves: (1) major structures which are all of timber and plywood; (2) multiple metallized-plastic copies of optically-worked off axis-paraboloidal glass moulds; (3) a hydraulic heliostat-tilting mechanism of novel design; (4) a laboratory, complete with high-vacuum equipment, mounted on the paraboloid casing, to be hoisted up the tower. (author's abstract)

\* \* \*

Goldstein, B.; Pensak, L., "High-voltage photovoltaic effect." *J. App. Phys.* **30**(2): 155-61, Feb. 1959. Illus.

Vacuum evaporated films of cadmium telluride have been prepared that show photovoltages as high as 100 v/cm of film length. The photovoltage saturates at high light intensities and low temperatures. At all other light intensities and temperatures it has the same functional dependence on light intensity as that of ordinary *p-n* junctions. Analysis of the data suggest a series of *p-n* junctions (or other photovoltaic elements) arrayed in an additive manner. Estimates of the linear density of photovoltaic elements based on the measurements described above vary from 200/cm at room temperature to 7000/cm at -170°C. A possible mechanism to explain the effect is proposed, based on an anisotropic growth of crystallites due to the angle of deposition, and on the pressure of residual gases in the vacuum chamber. (authors' abstract)

\* \* \*

Hammond, David A.; Shirland, Fred A.; Baughman, Richard J.; Harshaw Chemical Company, "A cadmium sulfide solar generator." *Wright Air Development Center, Tech. Rept. 57-770*, ASTIA Document No. AD 151036, Dec. 1957. 128 p. Illus. (PB 151276)

The efficiency of the CdS photovoltaic cells was increased to a range of 3 to 5 per cent from an average of 0.4 per cent by improved doping, growth, cleaning and electrodoping techniques. The method for making CdS cells is outlined. Two small solar generators were assembled from these cells for demonstration and testing purposes. Each of these gave about 50 mw of power at about 6-7 v when illuminated by direct sunlight. (authors' abstract)

\* \* \*

Heidt, Lawrence J.; Livingston, Robert S.; Rabino-witch, Eugene; Daniels, Farrington, "Introduction to the Symposium of Photochemistry of Liquids and Solids." *J. Phys. Chem.* **63**(1): 1-2, Jan. 1959.

Summary of the symposium held at Endicott House, Deadham, Mass., Sept. 3-7, 1957, on photochemical research into the practical utilization of solar energy.

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Hernqvist, K. G.; Kanefsky, M.; Norman, F. H., "Thermionic energy converter." *RCA Rev.* **19**(2): 244-58, June 1958. Illus.

Thermionic energy converter is a device for direct conversion of heat into electrical energy, having a high-work-function cathode and a low-work-function anode. This paper describes its operational characteristics and experimental studies of a converter having a tungsten cathode. Cesium vapor introduced into the tube serves two purposes. Cesium atoms ionized at the cathode surface cause space-charge neutralization in the interelectrode space. Cesium condensed at the surface of the cold nickel anode reduces the anode work function. Output voltage is 2.5 v; conversion efficiencies approximately 10 per cent. Materials problems and possible applications, at present limited to solar furnaces, are discussed. (authors' abstract)

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Kallman, H.; Pope, M., "Photovoltaic effect in organic crystals." *J. Chem. Phys.* **30**(2): 585-86, Feb. 1959.

In studies on the photoconductivity of anthracene, photovoltaic measurements on thin single crystals were made which appeared to be related to the studies on organic compounds involved in photosynthesis by Calvin and Kearns. One unusual aspect was the electrode configuration and composition when the anthracene crystal was positioned between and separated two 0.01 M NaCl solutions, which acted as transparent electrical contacts with each face of the crystal. An oxidation-reduction reaction appears to take place at the solution-crystal interfaces, and the splitting of water is accomplished by 3650 Å light through the intervention of the crystal. (authors' abstract)

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Loferski, J. J.; Rappaport, P., "The effect of radiation on silicon solar-energy converters." *RCA Rev.* **19**(4): 536-54, Dec. 1958. Illus.

The performance of silicon solar cells under simultaneous illumination and irradiation by various ionizing radiations

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has been observed for the purpose of estimating the useful life of such power sources in the environment of the I. G. Y. earth satellite. Results yielded an estimated minimum of about  $10^5$  years until the output of such cells on a satellite drops to 75 per cent of the initial value. Possible modifications of these estimates based on tentative data acquired from satellite flights have been considered. The decay of the cells is associated with changes in minority-carrier lifetime. No definite decay was observed during the limited exposure time of this study for the ultraviolet radiation between 2200 Å and 3400 Å or for x-rays from machines operated at 50-2000 kv. (authors' abstract)

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McQuigg, James D.; Decker, Wayne L., "Solar energy: a summary of records at Columbia, Missouri." *Missouri, Univ. Agr. Exp. Sta. Res. Bull.* 671, July 1958. 27 p. Illus.

Gives hourly and daily totals of solar radiation received, for the period 1944 to 1956.

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Maeris, George Jac, "Solar energy and sunshine hours at Athens, Greece." *Monthly Weather Rev.* 87(1): 29-32, Jan. 1959. Illus.

Measurements of the amount of solar energy in langleys and the number of sunshine hours, at the National Observatory, Athens, 1953-56.

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Mathur, K. N.; Khanna, M. L.; Davey, T. N.; Suri, S. P., "Domestic solar water heater." *J. Sci. Ind. Res.* 18A: 51-58, Feb. 1959. Illus.

Arrangement for heating water with solar energy for supplying the domestic needs of a small family at Delhi, using easily available and inexpensive construction materials (galvanized iron sheets). Details of construction are given and observations using heat collector unit with a single layer of glass taken during Oct.-Nov. 1955. Trials indicate domestic unit will recover initial cost in less than one year. (authors' abstract)

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Milner, G. J., "Solar furnaces: development at the N. S. W. University of Technology." Paper presented at the A.N.Z.A.A.S. Congress Solar Energy Symposium, Adelaide, Australia, Aug. 25, 1958.

Solar power, concentrated with a large high-grade concave paraboloidal mirror, has special advantages for heating materials to temperatures of 3000-4000° C, providing a "clean" method because a part only of a mass of homogeneous material need be heated to melting point. The arrangement of a paraboloid, inverted on a tower above a heliostat mirror on the ground, is commended. The influence of size on performance is indicated, as also is the problem of temperature measurement. (author's abstract)

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Morse, R. N. and Czarnecki, J. T., "The flat-plate absorber as a solar energy collector." Paper presented at the A.N.Z.A.A.S. Congress Solar Energy Symposium, Adelaide, Australia, Aug. 25, 1958. 10+ p. Illus.

The elements of a flat-plate absorber and the factors influencing its design and operation are reviewed. The thermal characteristics of energy received, losses, efficiency, and the heat transfer to the circulating fluid are dealt with in the light of design considerations. The effect of orientation and its influence on the evaluation of energy incident on inclined surfaces, the optimum angle of inclination, and the effect of changes in azimuth is considered. Installation and operating problems such as the prevention of damage by freezing, protection from hail, the location of an absorber and its materials of construction, and economic factors are discussed. (authors' abstract)

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Neuwirth, Otto S., "The photolysis of nitrosyl chloride and the storage of solar energy." *J. Phys. Chem.* 63(1): 17-19, Jan. 1959. Illus.

Nitrosyl chloride, dissolved in carbon tetrachloride, is photochemically decomposed by light below 6400 Å into nitric oxide and chlorine. The quantum yield is reduced by the reverse reaction, and values of 0.75 or less up to approximately 1.0 are obtained. Experiments using sunlight with a flowing system are described. The nitric oxide is insoluble and can be stored and later recombined with chlorine in carbon tetrachloride to give the original nitrosyl chloride and release some of the solar energy consumed in the photolysis. (author's abstract)

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Noyes, Richard M., "Kinetic complications associated with photochemical storage of energy." *J. Phys. Chem.* 63(1): 19-22, Jan. 1959.

If energy is to be stored in a photochemical process, the initial act of absorption of a photon must be followed rapidly by additional reactions. These can be classified according to whether or not a non-absorbing species must react either with the excited absorber or with a fragment formed from its dissociation. Because of the compressed time scale in which many of these additional reactions must occur, the kinetic treatment requires consideration of the special problems associated with very fast reactions. (author's abstract)

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Olgyay, Aladar; Telkes, Maria, "Solar heating for houses." *Prog. Archit.* Mar. 1959: 195-207. Illus.

A detailed outline of basic design considerations for houses heating by solar energy, including an analysis of the amount of solar energy that can be obtained at a particular location, compared to the heating loss of the house; a discussion of solar collectors and heating storage systems; the winter-summer balance; and design features in a solar house differing from conventional residences. Solar heating is compared with conventional systems from an economic point of view. Three recently-constructed solar houses are then described—the Lof house in Denver, MIT house in Lexington; and AFASE house in Phoenix.

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Parker, C. A., "Photoreduction of methylene blue. Some preliminary experiments by flash photolysis." *J. Phys. Chem.* 63(1): 26-30, Jan. 1959. Illus.

Dilute solutions of methylene blue in dilute sulfuric acid are reversibly bleached by flash photolysis, giving rise to two distinct transient species. One species produced by excitation with visible light has a lifetime of the same order as that of the flash and is tentatively identified as the lowest triplet state of the dyestuff. The second species is produced by excitation with light of short wavelength. Under conditions investi-

gated it has a lifetime of about 400 milliseconds. It is tentatively identified as the semi-quinone free radical produced by electron transfer from a water molecule. (author's abstract)

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Parker, C. A.; Hatchard, C. G., "Photodecomposition of complex oxalates. Some preliminary experiments by flash photolysis." *J. Phys. Chem.* **63**(1): 22-26, Jan. 1959. Illus.

Long-lived intermediates have been observed in solutions of the ferrioxalate, cobaltioxalate, and uranyl oxalate ions when they are subjected to flash photolysis. The compound produced in neutral ferrioxalate solutions disappears at a rate which is nearly independent of the concentration of ferrioxalate. Under these conditions, therefore, the rate-controlling stage is not the expected bimolecular reaction between radical and ferrioxalate, and the simple reaction scheme originally proposed is not sufficient to explain the results. Some possible additional rate-controlling stages have been considered, including dissociation of an excited ferrioxalate ion and dissociation of a complex between ferric iron, oxalate ion, and oxalate radical. As examples of systems involving efficient electron transfer reactions, both cobaltioxalate and uranyl oxalate, as well as ferrioxalate, are worth more investigation. (authors' abstract)

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Prince, M. B.; Wolf, M., "New developments in silicon photovoltaic devices." *J. Brit. Inst. Radio Engr.* **18**: 583-594, Oct. 1958. Discussion, p. 594-95. Illus.

Discussion and analysis of the performance of three types of *p-n* junction devices prepared by solid-state diffusion methods: (a) a solar cell, suitable for moderately low to high light levels, (b) a low level cell, and (c) a photodiode for low to high levels. Special response, transient response, and temperature dependence are considered. (authors' abstract)

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Rappaport, P., "New solar converter materials." (In: *Proceedings of 11th Annual Battery Research and Development Conference, May 22-23, 1957*. 4 p. Illus.)

Work at the RCA Laboratories on an investigation into materials for photovoltaic solar energy converters. Results are given for the operation of solar cells made with GaAs, InP and CdTe. Conversion efficiencies ranging from 2% to 6.5% were achieved.

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Riordan, R. H. S., "Selective surfaces for solar absorbers." Paper presented at the A.N.Z.A.A.S. Congress Solar Energy Symposium, Adelaide, Australia, Aug. 25, 1958. 6+ p. Illus.

The introduction indicates what a selective surface is, how it works, and what are its uses. The suggested methods for the production of a selective surface and the chosen process covering the plating operation, the preparation of the plate, and the properties of the product are outlined. The design and performance of an absorber employing selective surfaces and the practical value of selective surfaces is indicated. (author's abstract)

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Segal, A. I., "Solar furnaces: the pilot-model furnace at Broken Hill." Paper presented at the A.N.Z.A.A.S.

Congress Solar Energy Symposium, Adelaide, Australia, Aug. 25, 1958.

At Broken Hill, a 3-ft diameter furnace has been set up. Operating experience is reviewed and mention made of the studies in progress on a novel pyrometer device. (author's abstract)

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Sivertz, C., "Studies of the photoinitiated addition of mercaptans to olefins. IV. General comments on the kinetics of mercapton addition reactions to olefins including *cis-trans* forms." *J. Phys. Chem.* **63**(1): 34-38, Jan. 1959. Illus.

Some aspects of previous work are drawn together to illustrate some common problems in free radical kinetics with particular reference to termination. It is shown how useful information can be elicited by the study (a) of the attack of a common radical on various substrates and (b) of different radicals on a common substrate.

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Smith, D. H., "A one-watt solar power plant." Paper presented at the winter general meeting of the American Institute of Electrical Engineers, New York, Feb. 1958. 7+ p. Illus.

Describes some of the preliminary work with the Bell silicon solar battery that culminated in the field experiment at Americus, Ga., including exploratory device development and engineering studies. Preliminary tests are discussed and field test data are summarized.

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Speyer, Edward, "Optimum storage of heat with a solar house." Am. Machine & Foundry Co., Central Res. Lab., CRL-T-20, Apr. 28, 1959. 34+ p. Illus.

Explains a method for calculating the economic feasibility of solar house heating for different localities in the United States and presents results in terms of maximum cost per square foot of solar collector which can be afforded if the solar system is to be competitive. Sunny mountainous regions with cold winters are the most favorable areas.

Particular attention is given to the efficiency and capacity of energy storage and to the possibilities of saving summer heat for winter use. It is concluded that at present storage costs, such long-term storage is not economical. Storage costs of about \$1 per therm or solar collectors built and installed for \$1.50 per sq ft, would make solar houses economically attractive. (author's abstract)

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Telkes, Maria, "Research on methods for solar distillation." *Res. & Dev. Progr. Rept.* No. 13, for Office of Saline Water, Dec. 1956. 63+ p. Illus.

This study forms part of an investigation at New York University to reduce the total cost of converting saline water to fresh water in large quantities by solar energy through developing new methods and improving existing ones. Tilted flat stills previously developed and compared with roof-type stills were found to give a 26-50 per cent greater yield than estimated in the summer months. To explain the increased yield, heat transfer calculations were made and a sample calculation worked out for a flat tilted still. Calculations were confirmed with electrically heated stills. In the second part

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of the report, results of a study of the component parts of the tilted flat solar still, undertaken to improve their performance and decrease the cost of construction and materials, are summarized. Results of experiments with flat tilted, roof-type, and multiple-effect stills are tabulated.

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Thomas, J. B.; Nuboer, J. F. W., "Fluorescence induction phenomena in granular and lamellate chloroplasts." *J. Phys. Chem.* **63**(1): 39-44, Jan. 1959. Illus.

Fluorescence induction phenomena were studied in 7 species with granular chloroplasts and 7 with lamellate ones. The duration of the induction period was found to be shorter in the latter objects than in the former ones. In the discussion it was suggested that the stroma substance probably contains part of the photosynthetic enzymes and cofactors. (authors' abstract)

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Vavilov, V. S.; Malovetskaya, V. M. et al, "Kremnievi solnechni batari kak istochniki elektricheskogo nitiannya iskusstvennykh zemli." (Silicon solar batteries as sources of electrical energy for charging the artificial satellites.) *Usp. Fiz. Nauk.* **63**(1a): 123-29, Sept. 1957. Illus. English trans. given at the International Geophysical Year, Rocket and Satellite Conference, Washington, D. C., Sept. 30-Oct. 5, 1957.

Discusses silicon solar batteries as sources of electric power for telemetering and research instruments in artificial earth satellites.

\* \* \*

West, W.; Saunders, V. I., "Photochemical processes in thin single crystals of silver bromide; the distribution and behavior of latent-image and of photolytic silver in pure crystals and in crystals containing foreign cations." *J. Phys. Chem.* **63**(1): 45-54, Jan. 1959. Illus.

The distribution-in-depth of latent-image centers and of visible print-out centers has been investigated in purified thin crystals of silver bromide made from the melt and in crystals containing small additions of cadmium ion, lead ion, and cuprous ion. (authors' abstract)

\* \* \*

Wilson, Bruce W., "The role of solar radiation in the drying of peanuts." *Commonwealth Sci. Ind. Res. Org., Div. Ind. Chem.*, June 1958. 9 p. Illus.

Solar energy was used in drying peanuts both directly by absorption by the peanuts or indirectly by the transfer of solar heat from the air, in investigations carried out at Kingaroy, Queensland.

\* \* \*

Ziegler, Hans K., "Solar-power sources for satellite applications." *Ann. Int. Geophys. Year* **6**(3.3.3): 300-4, 1958. Illus.

Progress in the field of solar-power sources for satellites since 1956; investigations on silicon solar cells, improving their efficiency and determining their durability to high intensity radiation; energy storage devices; silicon-type solar power supplies designed and produced by the U.S. Army Signal Engineering Labs. for the Vanguard satellite program.

## ALSO NOTED

Abbot, C. G., "Long-range weather forecasting." *Smiths. Misc. Coll.* **138**(3), Feb. 16, 1959. 19 p. Illus.

— "Sun rays, power and weather." (In his: *Adventures in the world of science*. Wash., Public Affairs Pr., c1958. p.138-46. Illus.)

Anon., "RCA demonstrates solar cell using gallium arsenide." *Missiles & Rockets* **5**(19): 16, May 11, 1959.

Anon., "Singer's cast epoxy resin mirrors require no costly hand work." *Missiles & Rockets* **5**(9): 16, Mar. 2, 1959. Illus.

Anon., "Soviet solar switch." *Electron. Illus.* Jan. 1959: 66. Illus.

Aron, André, "Thermoelectricité des lames minces métalliques." (Thermoelectricity with thin metallic plates.) *Publ. Sci. Univ. Alger, Sci. Phys.* **4**(1): 33-46, 1958. Illus.

Baum, V. A., "Solar energy today & tomorrow." *UNESCO Courier* **11**(9): 4-6, Sept. 1958. Illus.

Behrme, R. L., "Reaching for the sun." *Better Homes & Gardens* **37**(2): 56-57, 146-47, Feb. 1959. Illus.

Behrman, Daniel, "The sun at work round the world." *UNESCO Courier* **11**(9): 7-17, Sept. 1958. Illus.

Caryl, Coleman R., "The langley as a unit for timing outdoor exposures." Paper presented at a meeting of the A.S.T.M. Committee D-11, Pittsburgh, Pa., Feb. 6, 1959. 9 p.

Chapin, Daryl M.; Fuller, C. S.; Pearson, Gerald L., "Solar energy converting apparatus." *U.S. Patent* 2,780,765, Feb. 5, 1957. 4 p. Illus.

Dormont, Henri, "Informe sobre mediciones solarimétricas." (Solar radiation measurements.) Centro Universitario Zone Norte, Universidad de Chile, 1958. p. 90-94.

Drummond, A. J., "Notes on the measurement of natural illumination. II. Daylight and skylight at Pretoria; the luminous efficiency of daylight." *Arch. Meteor. Geophys. Bioklim.* **A9**(2): 149-63, 1958. Illus.

Duff, Richard A., "Phoenix puts sun to work." *Phoenix Action* **14**(4): 1, 4-5, May 1959. Illus.

Edlin, Frank E., "Focus on the sun." *DuPont Mag.* **53**(2): cover, 2-5, Apr.-May 1959. Illus.

— "New materials for the utilization of solar energy." Paper presented at the Colloque International sur les Applications Thermiques de l'Energie Solaire dans le Domaine de la Recherche et de l'Industrie, Montlouis, June 1958. 21 p. Illus.

Elliott, J. Richard, "Tapping the sun; scientists have begun to put solar energy to work." *Barron's* **38**(51): 3, 16-18 Dec. 22, 1958.

Elmore, Glenn V.; Tanner, Howard A., "The photochemical properties of zinc oxide." *J. Phys. Chem.* **60**: 1328-29, 1956. Illus.

France, Ministre de l'Education Nationale, "De l'utilité des fours solaires." (On the utility of solar furnaces.) *Ing. Conseil France* **29**: 19-20, June 1958.

Frick, German, "Estudios sobre aprovechamiento energía solar en destiladores y cocinas." (Studies on the utilization of solar energy in stills and cookers.) Centro Universitario Zona Norte, Universidad de Chile, 1958. p. 94-102. Illus.

General Bronze Corporation Electronics Staff, "A universal antenna system for radio astronomy and space vehicle tracking." Paper presented at the 4th annual meeting of the American Astronautical Society, New York, 1958. Illus.

Hatchett, James L.; Marcus, Rudolph J., "A new electron acceptor for the Hill reaction." *Arch. Biochem. & Biophys.* **70**(1): 233-34, July 1958. Illus.

Hatsopoulos, G. N.; Kaye, J., "Analysis and experimental results of a diode configuration of a novel thermoelectron engine." *Proc. Inst. Radio Engr.* **46**(9): 1574-79, Sept. 1958. Illus.

Hatsopoulos, G. N.; Keenan, J. H., "Analysis of the thermoelectric effects by methods of irreversible thermodynamics." *J. App. Mechanics* **25**(4): 428-32, Dec. 1958. Illus.

Hounam, C. E., "Evaporation pan coefficients in Australia." (In: *UNESCO, Climatology and microclimatology; proceedings of the Canberra Symposium*. Paris, 1958. p. 52-60. Illus.)

Houston, J. H., "Theoretical efficiency of the thermionic energy converter." *J. App. Phys.* **30**(4): 481-87, Apr. 1959. Illus.

Howard, Seymour, "How solar and temperature studies guided design of sunshades for UNESCO headquarters." *Archit. Rec.* **125**(3): 226-29, Mar. 1959. Illus.

Juston-Coumat, Fridal, "Obtention et utilisation de l'ultraviolet à haute concentration." (Obtaining and utilizing ultraviolet at a high concentration.) *Publ. Sci. Univ. Alger* **B3**(1): 21-41, 1957. Illus.

— "Photo-transformations reversibles: système thionine-fer." (Reversible photo-reactions: thionine-iron system.) *Publ. Sci. Univ. Alger, Sci. Phys.* **4**(1): 47-60, Mar. 1958. Illus.

— "Sur l'obtention d'ultra-violet à haute concentration." (On obtaining ultraviolet at high concentration.) *Bull. Soc. Phys. d'Afrique du Nord*, 1957: 5-7. Illus.

— "Utilisation photochimique de l'ultra-violet à haute concentration." (Photochemical utilization of ultraviolet at high concentration.) *Publ. Sci. Univ. Alger* **B3**(1): 11-20. Illus.

Juston-Coumat, Fridal; Duburg, Maryse, "Le four solaire de Bouzareah." (The Bouzareah solar furnace.) *Bull. Engrais* No. 402: 8-9, Dec. 1957. Illus.

Kastens, Merritt L., "A chemist looks at solar energy." *The Chemist* **36**(1): 19-24, Jan. 1959.

Kelly, J., "Explanation of the mechanism of thermoelectric refrigeration." *Air Cond. Heat. Vent.* **56**(3): 89-91, Mar. 1959. Illus.

Krieg, E. H., "A look at the future in power station design." *Mech. Eng.* **80**(11): 66-70, Nov. 1958. Illus.

Lof, George O. G., "Profits in solar energy." Paper presented at the Energy Resources Conference, Denver, Colo., October 15-17, 1958 10 p.

Marcus, Rudolph J.; Hatchett, James L.; Sancier, Kenneth M., "Note on absorption spectra of Hill reaction oxidants." *Science* **127**(3299): 647-48, Mar. 21, 1958.

Masson, Henri, "Contribution à l'étude de l'échauffement de l'eau sous l'effet de la radiation solaire (2e note)." (Contribution to the study of heating water with solar energy.) *Dakar, Inst. Hautes Etudes Ecole Sup. Sci. Ann.* 1, 1954.

— "L'énergie solaire dans l'économie du monde actuel." (Solar energy in the economy of the world today.) *Ind. & Trav. Outre-Mer* No. 36, Nov. 1956. 6 p. Illus.

— "Les insulateurs à bas potentiel." (Low potential solar collectors.) *J. Phys. & Radium* **17**, supp. 6: 108A-110A, June 1956. Illus.

— "Le moteur solaire dans les régions arides." (The solar motor in arid regions.) *Bull. & Mém. Ecole Nat. Med. Dakar* **5**: 298-303, 1957. Illus.

— "Solar stills." *SPC Quart Bull.* Jan. 1957. 5 p. Illus.

— "L'utilisation de l'énergie solaire dans les régions tropicales." (Utilization of solar energy in tropical regions.) *Bull. & Mém. Ecole Med. Dakar* **3**: 244-51, 1955. Illus.

Mateer, C. L.; Godson, W. L., "A nomogram for the determination of solar altitude and azimuth." *Monthly Weather Rev.* **87**(1): 15-18, Jan. 1959. Illus.

McKelvey, V. E., "Resources, population growth, and level of living." *Science* **129**(3353): 875-80, Apr. 3, 1959.

Nagy, Akos; Vago, Pablo de, "Solar energy plant systems and method and equipment for operating the same." *Australian Patent* 216,523, June 21, 1956. 15 p. Illus.

Nebbia, Giorgio, "Primo symposium internazionale sulla demineralizzazione delle acque salmastre (Washington D. C., 4-6 novembre, 1957)." (First international symposium on the demineralization of saline water.) *Ricerca Sci.* **28**(6), June 1958. 10 p.

Neubauer, L. W., "Climatic studies on cooling the home." Paper presented at the Farm Structures Conference, Feb. 3, 1955.

— "Control of solar radiation." *Calif. Agric.* **9**: 14-15, July 1958. Illus.

— "Cooling principles for buildings." *Agrie. Eng. Dept.*, Davis, 012859. 5 p. Illus.

— "House cooling in a warm dry climate." California Project No. 1536, U.S.D.A. Project W-8, Oct. 20, 1955. 3 p.

Neubauer, L. W.; Cramer, Richard D.; Deering, R. B., "Temperature control for houses." *J. Home Economics* **50**(3): 175-84, Mar. 1958. Illus.

New York University, College of Engineering, Research Division, *Annual report*, 1958.

Nolan, Raymond M., "Sun to cool spaceship electronic components." *Missiles & Rockets* **4**(15): 39-41, Oct. 13, 1958. Illus.

Nottingham, Wayne B., "Thermionic diode as a heat-to-electrical-power transducer." *J. App. Phys.* **30**(3): 413-17, Mar. 1959. Illus.

Nottingham, Wayne B.; Hatsopoulos, George N.; Kaye, Joseph, "Addendum remarks on a diode configuration of a thermo-electron engine." *J. App. Phys.* **30**(3): 440-41, Mar. 1959. Illus.

Ozisik, Necati; Schutrum, L. F., "Heat gain through windows shaded by canvas awnings." *Heat. Pip. Air Cond.* **30**(5): 159-65, May 1958. Illus.

Peri, Georges; Perrot, Marcel; Robert, Jean, "Effets thermoelectriques présentés par certains oxydes. Etude de l'oxyde cuivreux." (Thermoelectric effects of certain oxides; study of copper oxide.) *J. Phys. & Radium* **18**: 282-83, Apr. 1957. Illus.

Perrot, Marcel; Peri, Georges, "Sur des éléments thermoelectriques particuliers." (On particular thermoelectric elements.) *Compt. Rend.* **239**: 537-39, 1954. Illus.

Perrot, Marcel; Peri, Georges; Robert, Jean, "Etude expérimentale d'effets thermoelectriques de certains oxydes pulvérulents." (Experimental study of the thermoelectric effect of certain pulverized oxides.) *Publ. Sci. Univ. Alger* **B3**(2): 107-20, Oct. 1957. Illus.

Perrot, Marcel; Peri, Georges; Robert, Jean; Tortosa, Jean; Sauze, André, "Sur un effet thermoelectrique présenté par de l'oxyde cuivreux en poudre." (On a thermoelectric effect with powdered copper oxide.) *Compt. Rend.* **242**: 2519-20, May 23, 1956.

Reinfeld, Fred, "The sun's energy." (In his *Rays, visible and invisible*. N. Y., Sterling Publishing Co., c1958. p. 7-27. Illus.)

Rusler, George W., "Nuclear or solar energy: which is more practical for space heating?" *Heat. Pip. Air Cond.* **31**(2): 106-9, Feb. 1959. Illus.

— "The world-wide energy outlook; part one of a study of solar energy utilization." *Minneapolis Honeywell Res. Rept.* Apr. 1958. 58 p. Illus.

Smithsonian Institution, Astrophysical Observatory, "Papers on the solar constant." *Smiths. Contrib. Astrophys.* **3**(3), 1958. 24 p. Illus.

Tarcicci, Adnan, "Solar heating apparatus." *U. S. Patent* 2,770,229, Nov. 13, 1956. 6 p. Illus.

— "Solar heating apparatus." *U. S. Patent* 2,770,230, Nov. 13, 1956. 4 p. Illus.

— "Sun-operated heating devices." *U. S. Patent* 2,760,482, Aug. 28, 1956. 3 p. Illus.

Touchais, Maurice, "L'utilisation industrielle du rayonnement solaire." (Industrial utilization of solar energy.) *Ing. Conseil France* No. 29: 9-18, June-July 1958. *Ibid.* No. 30: 11-22, Aug.-Sept. 1958. Illus.

U.S. Air Force Missile Development Center, Holloman AFB, N.M., *Solar furnace support studies*. Prepared by Scientific Consultants to the Operations Research Office under the direction of Knox Millsaps, Chief Scientist. Rept. AFMDC-TR-58-7; AD 135014, 1958. 210 p. Illus.

U.S. Bureau of Reclamation, "Solar distillation plant: schedule, general provisions, specifications and drawings." Saline Water Program, San Diego, Calif., Specifications No. DC-4902, 1957. 38 p. Illus.

Vinaccia, Gaetano, "Per uno studio del clima delle città: la necessità di una rete di rilevamenti meteorologici all'interno delle città." (Study of the climate of towns: the necessity for a net of meteorological stations inside towns.) *Geofis. & Meteor.* **6**(5-6), 1958. 2 p.

Webster, H. F., "Calculation of the performance of a high-vacuum thermionic energy converter." *J. App. Phys.* **30**(1): 488-92, Apr. 1959. Illus.

Whillier, Austin, "Engineering uses of solar energy." *EASA J.* **15**(5), Nov. 1958. Illus. 21 p.

— "Solar energy research." *Res. Rev. South African CSIR* **8**(3): 98-102, Sept. 1958. Illus.

Whillier, Austin; Richards, S. J., "Hot water from the sun." *Farmers Weekly* Nov. 19, 1958. 2 p. Illus.

Wilson, Bruce W., "The utilisation of solar energy." *J. Astron. Soc. Victoria* **10**(4): 55-57, Aug. 1957.

L.  
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